Methodological Exercise for testing a statistical approach to update a probabilistic seismic hazard assessment

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Executive Summary

The objective of this report is to present a Bayesian methodology, to update a probabilistic seismic hazard assessment based on a prior logic tree, and to conduct sensitivity analyses to check if the Bayesian update, based on observed data, may be used in the PSHA, to calibrate the weights of the different branches of a logic tree.

The PSHA carried out at the beginning of the SIGMA project is considered to generate the prior distribution of hazard curves at several selected sites. The predictions of acceleration exceedances rates are compared with the observations (accelerations recorded during the instrumental period, or obtained from correlations applied to historical events). Applying the Bayes theory, the conditional probability of occurrence of the predicted accelerations, given that instrumental or historical accelerations were produced, are used to calculate a posterior distribution of the weights of the different branches of the logic tree. The method is tested as an alternative to the classic weights assignment based on expert judgement. The posterior weights allow defining a posterior seismic hazard assessment (mean and centiles seismic hazard curves), which is assumed in better agreement with the observations, and for which a reduction of the uncertainties is expected.

The prior probabilistic model used to apply the methodology corresponds to the logic tree developed during the preliminary phase of SIGMA project (Carbon et al 2012a, 2012b) and composed by 24 main branches.

A database, called REX (Return of Experience), was developed for this project. It must be seen as a prototype necessary for the exercise, and researches are in progress to elaborate a more reliable database. The REX contains the ground motion data recorded at stations of the National accelerometric network and the synthetic or estimated strong motion data generated using the French historical database SISFRANCE (BRGM, EDF, IRSN). From this database, we selected earthquakes from the last five centuries, with epicentral intensity above or equal to V and generated the PGA through two methods:

- An intensity prediction equation, function of the epicentral intensity and distance, to determine the intensity at each considered site and conversions between macroseismic intensity and PGA.
- 2 GMPEs, one based on a stochastic approach and developed in the framework of the SIGMA project for the French territory (Drouet, 2013) and the empirical GMPE of Cauzzi and Faccioli (2010). In this case considered the SIGMA catalogue homogenised in Mw.

The REX database was not used to carry out the preliminary SIGMA PSHA, which generates the prior distribution of the hazard curves.

Different sensitivity tests are conducted to implement the Bayesian update, using different set of observations from the REX and several acceleration thresholds. They allow to identify some basic rules if we intend to apply the approach for applications and suggestions of improvements.

A specific software was developed to implement the Bayesian update. It allows the upload of any prior logic tree, the statistical analysis and treatment of the REX database to apply different filters, the application of the Bayesian update and the post-treatments after generation of the posterior weights distribution.

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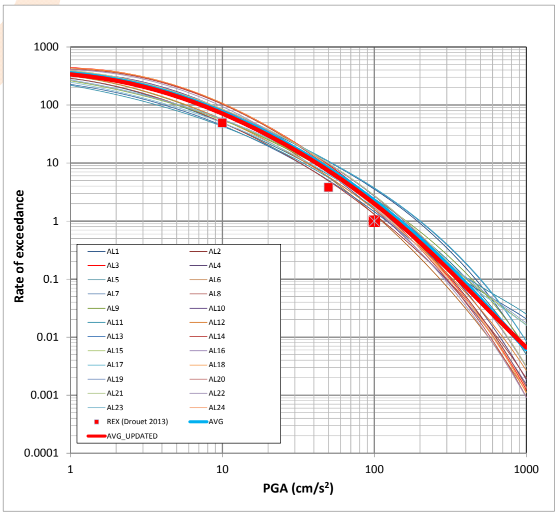

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1. INTRODUCTION

1.1 CONTEXT

Considering the high uncertainties in Probabilistic Seismic Hazard Assessments (PSHA) and the importance of PSHA results for the seismic design, it is pertinent to focus on the issue of consistency-checking of the PSHA results. In 2008, the OECD/NEA (OECD Nuclear Energy Agency) in cooperation with the IAEA organized a workshop on Recent Findings and Developments in PSHA: Methodologies and Applications (OECD/NEA, 2008). The main objective was to review recent research, and regulatory and industry issues associated with the PSHA methodology. Two main recommendations were addressed:

- The importance of undertaking consistency checks, which can provide valuable information, even though they are substandard to what a validation would be. Guidance on consistency checks should also be a major part of any broader PSHA; and
- Using Bayesian updating methods in this area is to be encouraged. It can be of important value and help further PSHA work (both research work and applications).

In the last decade several approaches to test PSHA results have been published (i.e. Sterling et al 2006, 2009, 2010, 2012; Mucciarelli et al 2008; Musson et al 2010; Mezcua et al 2013) and several studies applied the Bayesian technique to update PSHA models (i.e. Humbert and Viallet 2008, Selva and Sandri, 2013). Also, several recent opinion papers are encouraging hazard analysts to carry out tests of PSHA results. And testing applications have been done in different countries (United States, New Zealand, Italy, and France). The techniques rely on various statistical assumptions. Any testing technique must deal with the observation time window available. Considering the observation time window in seismology testing (a maximum of approx. 100 years for instrumental networks and several centuries for historical data), and the return periods of interest in engineering seismology (in the order of thousands of years), the comparison of observations and predictions is a real challenge.

Recent literature shows that PSHA models can be evaluated using different types of observations, such as intensities, synthetic accelerations (converted from intensities or predicted from an earthquake catalogue), and recorded accelerations at instrumented sites.

In 2007, a PSHA study was performed in France, at a national scale, developed in terms of macroseismic intensity (Carbon et al 2007). Using this PSHA study, a comparison of predictions and historical observations (French Sisfrance database) was performed and resulted in a rather good agreement. However, this consistency is not observed when the PSHA is developed in terms of acceleration.

When conducting the PSHA developed in terms of intensity, the intensity prediction equations were calculated using the local macroseismic data from the national database and the seismic distribution relations (Gutenberg-Richter model) were developed using the earthquake catalogue homogenized in intensity.

In a PSHA developed in terms of acceleration, the seismic distribution relations (Gutenberg-Richter model) are always developed using local data. However, in a context of moderate activity, the ground motion prediction equations (GMPE) are imported from worldwide databases or from regional databases representative of other seismotectonic contexts. There were not enough seismic records in stable seismotectonic regions (such as France) to develop a local GMPE. This could be one of the reasons of the discrepancies between predictions and observations. Of course, in the case of intensities, we have a longer period of observation (some centuries). In the case of accelerations, the period of observation is only some tens of years. This short period of observation could also be a reason of the discrepancies between predictions and observations.

The Bayesian approach presents a methodology to analyze the discrepancies between predictions and observations.

1.2 OBJECTIVES

In recent years, increasing efforts have been devoted to the assessment of the reliability of PSHA results. Different procedures have been tested and many publications have provided useful information on this subject (e.g. Selva and Sandri, 2013; Mezcua et al. 2013; Humbert and Viallet, 2008).

The objective of this report is to present to the SIGMA scientific community (geologists, seismologists, statisticians, and engineers) a Bayesian methodology for testing probabilistic seismic hazard analyses (PSHA) and for justifying an alternative approach to determine the logic tree weighting scheme. The goal of this study is to present only the general methodology, without presenting a formal application. This methodology has been developed in the spirit of updating any PSHA study.

We present a general Bayesian methodology in which the results of different probabilistic models included in a logic tree and the recorded data (which are independent from the data used in the PSHA) are used together to try reducing the uncertainties in a PSHA. In this sense, the main objective is not to develop a new PSHA model (we used an available model), but to allow, through a Bayesian approach, the explicit evaluation and comparison between predictions and observations to offer a rational approach to modify the prior weights of a logic tree.

In recent PSHA studies, the uncertainties are commonly propagated using complex logic trees. The weights of the different branches of the logic tree are commonly defined using expert judgment. The Bayesian methodology allows defining the weights of the different branches of the logic tree by means of a comparison with observed seismic data not used in the PSHA. Any of the reliable scientific hypotheses retained in the logic tree is rejected. Only the weight is modified using objective criteria, instead of subjective criteria, such as expert judgment.

The Bayesian updating method suffers from recurrent criticism:

- Period of observation: The instrumental period is often estimated too short to update a PSHA. In regions of moderate activity the number of years of observation must be large enough, to compare predictions and observations on a large range of accelerations.
- Threshold of acceleration: In stable seismotectonic areas, the acceleration records correspond to low PGAs (or pseudo-spectral accelerations [PSA]). It is generally deemed not appropriate to use low acceleration thresholds to update the complete seismic hazard curve (from low to high accelerations).
- Region of observations: To increase the observation window, the data from accelerometric seismic stations belonging to different seismic contexts are often considered to update the hazard at sites located hundred kilometers away from the observations. The use of data recorded in a region with seismotectonic context different from the site's context is deemed not appropriate.

In conducting a Bayesian approach, double use of seismic data (in the prior model and in the update) must be avoided. For example, the strong motion records used to develop a given GMPE should not be used for updating purposes of a PSHA that used this GMPE. It's required that the data used in the evaluation (or update) of the model should not be involved in the input for the model development (Stirling and Gerstenberger, 2010). This is the case of recorded strong motions in France, which were not used in the development of the GMPEs used in the prior PSHA model. This is also the case of intensity values, which were only used for the magnitude evaluation of the historical earthquakes.

In this study, we will try to increase the number of years of observation and the threshold of recorded acceleration developing a synthetic historical REX (*Return of EXperience*, based on observations). It is created using the historical earthquake catalogue of France (Sisfrance). The use of the historical REX will also allow using higher PGA levels (associated with higher return periods) to update the seismic hazard.

The REX is only a prototype and a tool to support the exercise and it is not intended to be a definitive database of recorded observations. It has been developed within the South-East of France to update the seismic hazard at sites located in the SIGMA region of interest.

The main objective of this study is to present a new Bayesian methodology to update the seismic hazard. The report is structured as follows:

- In chapter 2, we summarize publications proposing Bayesian updating methods or presenting comparisons between observations and predictions.
- Chapter 3 presents the mathematical methodology supporting the Bayesian approach.
- In chapter 4, we present the prior model.
- In chapter 5, we present the compiled REX, which can be filtered to generate sets of observations.
- Chapter 6 presents sensitivity tests.
- Chapter 7 presents the conclusions and perspectives of the methodology.

2. REVIEW OF SIMILAR METHODOLOGIES

2.1 SELVA & SANDRI (2013)

References:

Selva J. and L. Sandri. Probabilistic Seismic Hazard Assessment: Combining Cornell-Like Approaches and Data at Sites through Bayesian Inference. *Bulletin of the Seismological Society of America, Vol. 103, No. 3, pp. 1709–1722, June 2013.*

This paper proposes a new PSHA methodology based on a Bayesian approach. The prior data correspond to the probabilistic models from a classical PSHA (using Cornell's methodology). They are compared with data coming from a macroseismic investigation (REX). This Bayesian methodology allows an increase in accuracy (or decrease in bias) of the posterior PSHA results.

They showed the applicability of the proposed methodology by providing an illustrative example of updating a PSHA in a wide area, the Emilia–Romagna region, in northern Italy. Because they have relied only on data available online, they remark that this was only a tutorial example, and by no means intended for use in earthquake engineering. They outlined that the methodology could be used for other types of PSHA, such as for critical facilities or for longer time windows.

The mathematical method is different from the approach proposed in this study. Nevertheless, the concept is similar. The method takes a prior PSHA results and then compares the information of this PSHA with observed data. Firstly, they have the seismic hazard curves in a grid of points. Secondly, they developed a REX database. The method consists in the calculation of the probability of exceedance of a PGA of 0.1 g. This probability is calculated from the macroseismic information. They calculated also the period of completeness of this information. They estimate that a PGA of 0.1 g cannot be produced by intensities lower than V (intensity scale MSK-64), The period of completeness of intensity V is then used. Finally, they calculate the number of exceedances of this PGA in each point of the grid, for time windows of 50 years. The Bayesian method allows updating the seismic hazard in each point of the grid where the seismic hazard is calculated.

The paper describes two types of Bayesian update. One of them is calculated using the data in each one of the grid points. The second type is calculated using only past data for sites with complete historical record (mainly in cities).

The posterior map in the first case shows a decrease of the seismic hazard. In the second case, the use of a limited number of observations implies that the updating process is not affecting the prior seismic hazard. This could be considered normal. If there is no data (or limited data) to compare with, or if the time window to merge the a priori seismic hazard curves with the observed data (REX) is short, the updating process is not effective.

As it will be explained in the following chapters, this is an expected effect of the Bayesian updating approaches: the greater the period of observation and the number of observations, the higher the effects in the prior seismic hazard assessment.

Even if the goal of this application is only the tutorial of the presented method, rather than an analysis for a seismic design, it constitutes a demonstrative example of the possibilities of a Bayesian updating approach.

2.2 MEZCUA ET AL. (2013)

References:

Mezcua J., J. Rueda, and R. M. García Blanco. Observed and Calculated Intensities as a Test of a Probabilistic Seismic-Hazard Analysis of Spain. *Seismological Research Letters Volume 84, Number 5 September/October 2013*

This article presents a methodology to compare the observed and/or estimated data to an existing PSHA. It doesn't present a methodology to update the PSHA (as it is presented in Selva and Sandri [2013] or in our approach.

In Spain, earthquake activity is considered moderate with only a few large events separated by long periods of time. Moreover, the strong-motion network is recent, with very few recorded acceleration values. These facts make it difficult to compare the observed values with the corresponding hazard curve for a specific location. However, the use of intensity data provides a potential basis for calculating strong ground motion data. As intensity recordings are not complete for the historical time period, they estimated the periods of completeness of the selected intensities.

The REX contains two different types of data: real and calculated data. Firstly, the intensities recorded in 19 cities were compiled for further comparisons with a PSHA. Secondly, to corroborate such intensity values at a specific site, they developed another set of calculated or synthetic intensities. They were obtained using a relation specifically developed for the Iberian Peninsula (Mezcua et al., 2004). The relation allows getting the intensity from the moment magnitude and the distance between the epicenter and the site. Finally, these intensities felt at the sites are converted to peak ground acceleration using the relation of Atkinson & Kaka (2007).

At the selected sites, the annual frequency of exceedance (AFE) of the EMS intensities 5, 6, 7, 8, and 9 converted to ground acceleration were compared to the values of seismic hazard presented in the latest publication of a PSHA study in Spain. From this PSHA, they obtained the seismic hazard curves at the 19 sites and compared the seismic hazard curves predicted by the PSHA to the observed and calculated annual frequency rates.

The comparison showed rather good agreement of predictions and observations in the majority of the 19 sites studied.

The authors pointed out that the results of the comparison should be interpreted with caution because factors like the intensity–acceleration relationship, completeness dates, or site effects may introduce errors that overshadow the final results.

2.3 HUMBERT AND VIALLET (2008)

References:

HUMBERT and VIALLET, 2008. A method for comparison of recent PSHA on the French territory with experimental feedback. The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China

The purpose of this study was to compare a PSHA for the French territory with experimental feedback (REX) and to give a point of view on the confidence in probabilistic models of seismic hazard based on observations. The considered PSHA was compared to seismic experience feedback provided by the survey system of EDF (Electricité de France) sites and by the RAP (French accelerometric network).

The two prior PSHA's considered in this paper are: (i) the study published by MEDD (French ministry of environment and sustainable development) in 2002 and (ii) the study conducted by AFPS (French association of earthquake engineering) working group in 2006.

This paper developed a methodology based on a probabilistic approach which allows comparing prior PSHA's with observations at EDF Nuclear Power Plants (NPPs) and at several RAP stations. The methodology used in Humbert and Viallet (2008) is, in many aspects, similar to our approach except that the REX was composed only with instrumental records (e.g. a limited duration of observations) and conducted at the territory level. Some corrections terms were included:

1. One correction factor due to Site Effects and Soil-Structure Interaction at NPP site, as the recording stations were not in the free field.

2. one due to the limits of the experimental feedback: (i) the random variability of earthquake occurrence due to the limitations of observation period is accounted for, and (ii) the inter-correlation between different sites is accounted for by a negative binomial distribution.

The application of the methodology showed that the MEDD 2002 PSHA, which was developed incorporating few epistemic uncertainties, was inconsistent with experimental feedback. The AFPS 2006 PSHA model (where more epistemic uncertainty was considered) was more consistent with the experimental feedback regardless that it seems to overestimate the hazard.

2.4 HEINFLING ET AL. (2005)

References:

Grégory HEINFLING*, Alexis COURTOIS, and Emmanuel VIALLET. Reliability based approach for the ageing management of prestressed concrete containment vessel. *18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18). Beijing, China, August 7-12, 2005. SMiRT18-H06_5*

This article presents a methodology to analyze the long term creep and shrinkage prediction of a concrete wall of the inner containment of the French 1300/1450 MWe pressurized water reactors. The proposed approach allows updating based on the available strain measurements. This method allows obtaining an updated statistical distribution of the delayed strain. The modelling of the delayed behavior is based on a physical model which accounts for the decomposition of creep and shrinkage physical mechanisms. The uncertainties on the corresponding physical parameters are accounted for by coupling this model with a classical probabilistic method. The updating of the initial prediction on the base of the measured delayed strains is performed trough a Bayesian technique.

This method is conceptually the same as that presented in this report to update the seismic hazard. The idea is to update a probabilistic prediction of the concrete behavior during the lifetime of the nuclear power plant using real measurements performed during the first years of the operation of the utility. In the case of seismic hazard, we have a probabilistic model predicting exceedance rates of acceleration levels and we have some observed or estimated accelerations. The objective of comparing predictions and observations is to better constraint the seismic hazard, reducing the existing uncertainties.

Therefore, the updating method presented in our report is not a complete new methodology. It could be considered as an adaptation to the seismic hazard of Bayesian updating methods used in other engineering disciplines.

3. METHODOLOGY

3.1 MATHEMATICAL DEVELOPMENT OF THE BAYESIAN UPDATING APPROACH

The Bayesian approach developed to update the seismic hazard is based on the comparison of the exceedance rates of acceleration thresholds predicted by the probabilistic models of a logic tree (seismic hazard curves) and the exceedance rates observed from available records (recorded or synthetic) in a seismic network stations.

The method uses the Bayes theorem. Following this theorem, the conditional probability of occurrence of an event A, given that other event B was produced, is defined by:

$$P(A/B) = \frac{P(B/A).P(A)}{P(B)} \quad (1)$$

Applying the method to the seismic hazard, we can replace A by the exceedance rate of a fixed acceleration threshold predicted by a probabilistic model (this information is typically provided by the seismic hazard curves) and B by the exceedance rate of the same acceleration threshold following the available observations (called here REX or return of experience). Then:

$$P(Model/Observation) = \frac{P(Observation/Model).P(Model)}{P(Observation)} \quad (2)$$

In a logic tree with N branches defining N input models of a calculation of seismic hazard, the weight given to each branch of the logic tree is equivalent to the probability of the model, P(Model). The updating method consist on calculating the conditional probability of each model knowing the observations included in the REX, P(Model/Observation), that determines the a posteriori value of the weight of the logic tree branch.

If the method is initialized considering that the N branches of the logic tree are equivalent (equal probability), then the weight of each logic tree branch (or the probability of a model « i ») is:

$$P(Model_i) = \frac{1}{N} \quad (3)$$

The objective consists in quantifying the following part of equation (2):

$$\frac{P(Observation/Model)}{P(Observation)} \quad (4)$$

P(Observation) is independent on the models and is equivalent to a normalization factor. Then, the sum of P($Model_i$/Observation) is equal to 1 (sum of weights a posteriori = 1). Performing the integration of equation (2) on the set of N models/branches of the logic tree, we have that:

$$\sum_{i=1}^{N} P(Model_i/Observation) = \frac{1}{N} \times \frac{1}{P(Observation)} \times \sum_{i=1}^{N} P(Observation/Model_i) = 1 \quad (5)$$

Therefore,

$$\frac{1}{N} \times \frac{1}{P(Observation)} = \frac{1}{\sum_{i=1}^{N} P(Observation/Model_i)} \quad (6)$$

To define P(Observation/Model$_i$), the model of earthquakes occurrence is supposed to follow a Poisson distribution with parameters λ and t :

$$P(n,t) = \frac{e^{-\lambda t}(\lambda(M)t)^n}{n!} \quad (7)$$

P(n,t) is the probability to observe n earthquakes of magnitude greater than M during a period of observation t, and λ is the annual exceedance rate of these earthquakes.

If the recording stations are supposed to be independent, the probability to observe the exceedance of an acceleration level follows a Poisson distribution law (Beauval et al., 2007).

Nevertheless, if the occurrence of an earthquake of magnitude M implies the exceedance of an acceleration level at some stations, then there is a correlation among the different stations. The exceedance of an acceleration level follows, in this case, a more general distribution, the negative binomial distribution:

$$P(Observation/Model_i) = \exp\left[\ln\Gamma\left(\frac{A_i}{k-1}+N_{REX}\right)-\ln\Gamma\left(\frac{A_i}{k-1}\right)-\ln\Gamma\left(N_{REX}+1\right)\right]\times\frac{1}{k}^{\frac{A_i}{k-1}}\times\left(1-\frac{1}{k}\right)^{N_{REX}} \quad (8)$$

- Ai is the number of exceedances of an acceleration level, A*, predicted by the probabilistic model « i » on the global set of sites of stations of REX :

$$A_i = \sum_{j=1}^{L}\lambda_{ij}\left(A^*\right)\times T_j \quad (9)$$

- L is the number of selected stations of REX, Tj is the cumulative number of years of observation at station « j », and λ ij (A*) is the exceedance rate of acceleration level A* fixed by the seismic hazard curve calculated at the site of station « j » following the probabilistic model « i ».
- The parameter k is indicative of the correlation among stations of the REX. If k tends to 1, the negative binomial distribution goes towards a Poisson distribution. The parameter k is the average number of sites impacted by one earthquake.
- NREX is the number of total exceedances of the acceleration level A* observed (recorded) at L stations of REX.

We obtain finally that:

$$P(Model_i / Observation) = \frac{P(Observation/Model_i)}{\sum_{i=1}^{N} P(Observation/Model_i)} \quad (10)$$

And P(Model$_i$ /Observation) represents the weight of the model *i* in the logic tree.

3.2 MAIN REMARKS ON THE METHODOLOGY

The updating method of the seismic hazard modifies the "*a priori*" weight or probability of each probabilistic model P(Model$_i$)=1/N with the "*a posteriori*" weight defined by equation (10). These updated or posterior weights are adopted to weigh the results and to calculate a new seismic hazard (median, mean and centiles 15% and 85%).

Therefore, the updating method of the seismic hazard doesn't affect the individual calculation of the exceedance rates of the acceleration levels predicted by the prior probabilistic seismic hazard curves. It only adjusts the weights associated with each probabilistic model. Thus, the updating method only changes the final mean, median and centiles seismic hazard curves. These statistical values (seismic hazard curves) are affected by the weights assigned to the individual seismic hazard curves of the individual models.

The software developed in the framework of SIGMA project, allow performing the updating of the seismic hazard defined by a logic tree containing N branches with *a priori* weights equal to 1/N, using the comparison with a fixed set of observations (REX).

Note that the updating is performed using a comparison of probabilistic predictions with recorded and/or estimated observations (REX) at L stations. From this comparison we obtain new weights (or probabilities) of the N branches of the probabilistic logic tree. After the definition of the N posterior weights, we post-process the probabilistic results considering the new weighting scheme, to calculate new seismic hazard curves at the same observation points of the REX.

The choice of the stations for the analysis of the REX could have a significant impact on the posterior weights of the branches. The final seismic hazard curves could vary depending on the stations selected to build the REX.

For this reason, the selection of the REX is an important part of the updating method. The considered REX must be representative of the study region and, preferably, it should cover the largest possible period of observation.

3.3 SOFTWARE DEVELOPED FOR APPLICATION PURPOSES

To facilitate the application of the Bayesian updating method, an in-house software was developed. It is based on several research projects developed during 2007 and 2008 (Viallet et al., 2007; Humbert and Viallet, 2008; Viallet et al., 2008). The software developed during this project, called *Bayac14, includes* 2 main interfaces:

- *The first interface allows the statistical analysis and management of the REX*. It allows reading the global REX and implementing analyses, e.g. applying filters. Thus, it is possible to create partial REX databases depending on the filters used. For example, the user could select, from the global REX, only the recorded information at a selected station, corresponding to earthquakes of magnitude equal or greater than 5.0, with PGA values greater or equal than 0.010 g during the last 10 years.
- *The second interface is related to the Bayesian updating method*. It allows updating the seismic hazard using, as input data, the probabilistic models of a logic tree (that can be loaded by the user) and a REX defined by the user.

The annex 1 describes the main capabilities of the software.

4. PRIOR MODEL

One of the objectives of this study was to apply the methodology to a case study. We considered the logic tree developed during the initial phases of the SIGMA project (Carbon et al 2012a, 2012b).

It contains 24 main logic tree branches (Carbon et al 2012b). These branches were associated with:

- Three seismotectonic models (MS1, MS2 and MS3)
- Four GMPEs or attenuation relations (Akkar and Bommer 2010; Boore and Atkinson, 2011; Zhao et al., 2006, Berge-Thierry et al., 2003).
- Two seismic catalogues (C1 and C2)

The combination of these hypothesis leads to the definition of 3 x 4 x 2 = 24 main branches.

At the end of each main branch characterized by a seismotectonic model, a GMPE and a seismic catalogue, there are N secondary branches in order to propagate the uncertainties associated with the seismic parameters of the seismotectonic sources (λ and β of the Gutenberg-Richter law, maximum magnitude, Mmax, and thickness of the seismogenic crust, H). Finally, the global logic tree defined for the SIGMA project was composed by 24 x N logic tree branches.

As the purpose of our analyses is to verify the applicability of the Bayesian update, we decided to use only the main logic tree branches (24 main branches). This considerably decreases the calculation time and allows focusing on sensitivity tests. Each of these branches considers a seismotectonic model, a GMPE, a catalogue and the mean seismic parameters of each seismic source. This choice was made to simplify the analysis of the results. Nevertheless, the Bayesian method can be applied to any more complex logic tree.

The minimum magnitude considered in the PSHA used for the test is Mw=4.5. For this reason, the REX (number of observations at the selected sites) should take into account only events with magnitudes greater than 4.5.

5. DEFINITION OF THE REX DATABASE

5.1 REX INSTRUMENTAL

The instrumental REX file containing the acceleration records of the French seismic network (*Réseau Accélérométrique Permanent*, RAP) has been provided by EDF (file Rap-SelectedDataList.xlsx).

The file contains 970 acceleration records (965 records have complete information). 232 records come from earthquakes with magnitudes equal or greater than 4.5. The maximum PGA recorded (SAOF station) was 117 cm/s^2 and only 71 records have a PGA greater than 10 cm/s^2.

The French seismic network is composed by 84 stations across the entire French territory (Figure 1). The first station was installed in 1995 (OGGM and OGDI). The majority of the stations are located in the most active seismic areas of France: the Alps and the Pyrenees.

The file containing the instrumental REX was reformatted to include all required fields. The new file is called REX_INS.rex.csv and it contains the following information:

- EVENTID: it is the identifier of the record.
- TY_SEISMICITY: It defines if the record is historical or instrumental
- CO-STATION: name of the station
- RESEAU_STATION: name of the seismic network (RAP in our case)
- LAT_STATION, LON_STATION: geographical coordinates of the recorder
- TY_SOL_STA: type of soil where the station is installed.
- PER_FONC: period of time of operation of the station.
- ANNEE, MOIS, JOUR, HEURE, MINUTE and SECONDE: These fields contain the date and time of the record.
- LAT_SEISME, LON_SEISME: geographical coordinates of the epicenter.
- PROF_SEISME : depth of the earthquake
- DT_EPICENTRALE : epicentral distance
- MAGNITUDE : magnitude given by RAP network
- PGA_N, PGA_E, PGA_Z: It is the PGA recorded in each 3D component
- INT_EPICENTRALE: epicentral intensity in the French seismic catalogue.
- CO_RELATION_IE_IS: It indicates the relation used to convert the epicentral intensity to site intensity.
- INT_SITE : It indicates the punctual intensity at the station
- CO_RELATION_IS_PGA: It indicates the relation used to convert the punctual intensity to PGA.
- VF_OUT_VALIDITE: It indicates if the record is out of the validity domain (according the period of operation and date of occurrence). It is useful for the historical REX. In the case of Instrumental records is useless.

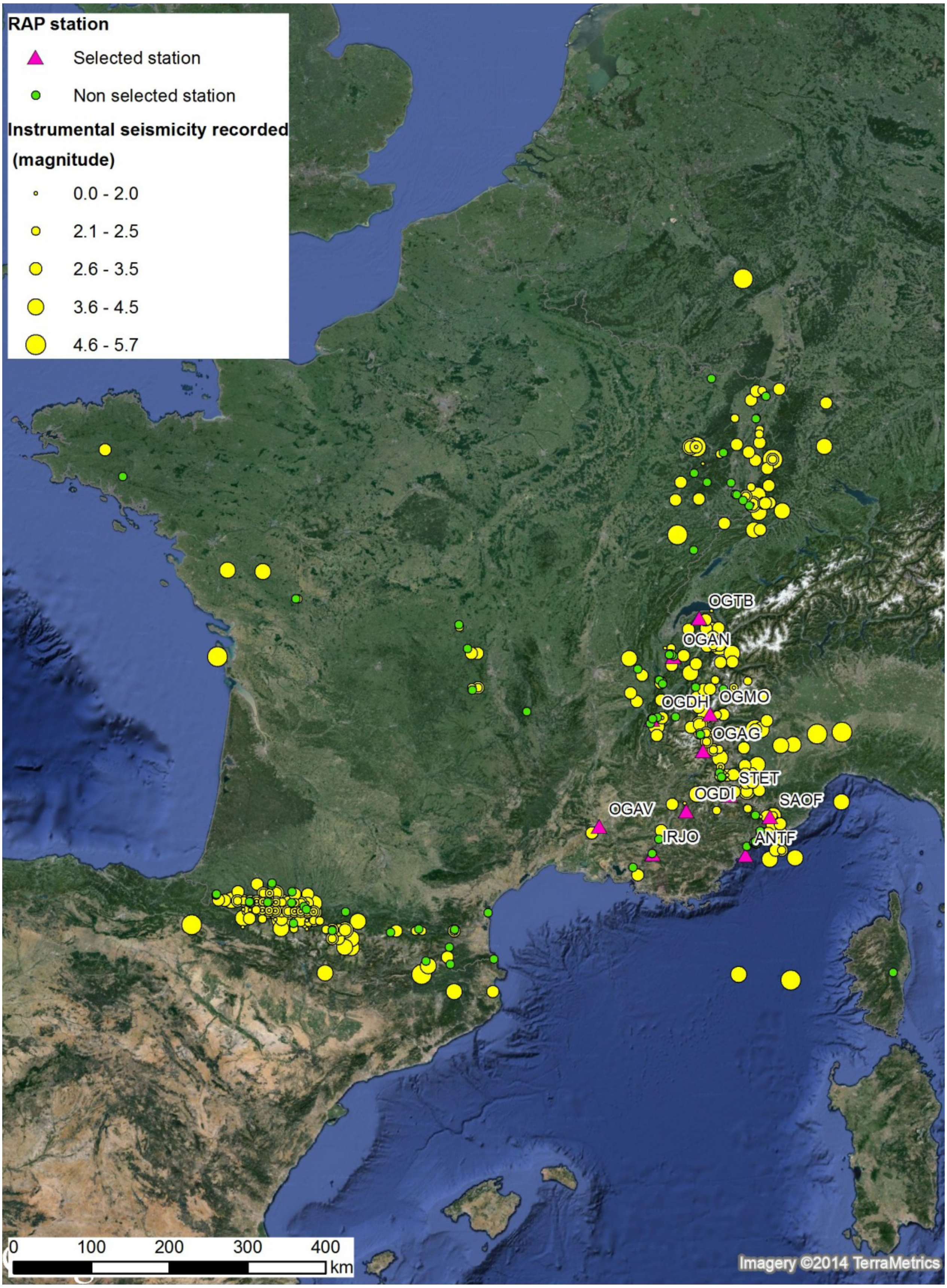


Figure 1. Seismic stations of the French seismic network, RAP (green dots) and earthquakes included in the instrumental REX (yellow dots). The pink triangles correspond to the selected RAP stations in the SIGMA region.

5.2 HISTORICAL REX

The historical REX was developed using the *Sisfrance* database. It contains 1700 intensity records from year 463 to end of 1961. 1141 records have an epicentral intensity equal or greater than V (Figure 2). Intensities lower than V were removed.

The objective of the historical REX is to calculate the *hypothetical* or *synthetic* acceleration values probably generated at the stations of the REX during the historical events. The generation of *synthetic* accelerations has been performed as follows:

1) Calculation of epicentral distance from the earthquake epicenters to the recording station.

2) Calculation of peak ground acceleration (PGA) values that would have been probably generated at the stations. The acceleration values can be obtained using 2 methods:

   a. Calculation of punctual (or site) intensities at the stations using intensity prediction equations defined in terms of epicentral intensities and epicentral distances (i.e. Mezcua et al., 2004; and Martin et al., 2008; Carbon et al 2007). Then, acceleration values are calculated using the punctual intensity and appropriate intensity-PGA relations (i.e. PS92; Gomez and Capera, 2007; Atkinson and Kaka, 2007; etc.). This is the methodology used, for example, by Mezcua et al. (2013).

   b. Calculation of acceleration values using GMPE's. We used the GMPE of Drouet (2013), specially developed for France during the SIGMA project, and Cauzzi and Faccioli (2008).

Firstly, using geographical information systems (GIS), the epicentral distance from each one of the 1141 historical earthquakes retained to the 84 RAP seismic stations were calculated (Figure 2). To build the historical REX database we only retained those records with an epicentral distance lower than 150 km. For larger distances, the intensity and the peak ground acceleration at the site is too low to be considered for an updating process.

The final historical REX contains 12549 synthetic PGA records (file REX_2014_HIS.rex.csv). These synthetic records correspond to the hypothetical recorded data at the RAP seismic stations located less than 150 km from the epicenter.

When the epicentral distance and the epicentral intensity are included in the database, the punctual intensity probably felt at the site (punctual intensity) can be calculated using appropriate attenuation relations in terms of intensity. In the software developed in this study, we included the 7 attenuation relationships calculated by Secanell et al 2007. Among the 7 Intensity Prediction Equations, one developed for the Alpine region is selected for this study.

Finally, from the punctual intensity, the PGA probably felt at the site could be calculated. In the literature, there are several equations to convert intensity to PGA (e.g. Gomez Calpera, 2006; Panza 1997; Faccioli and Cauzzi, 2006). These relations and other were introduced in the software (*Bayac14)*. We used these relations to generate estimated PGAs.

In our software, the synthetic PGA "*probably generated*" or estimated at the stations can be also calculated using the GMPE of Drouet (2013) (specially developed for the French territory during the SIGMA project) and Cauzzi and Faccioli (2008) GMPE. The PGAs are calculated using the moment magnitude and the epicentral or hypocentral distance. The magnitude of historical earthquakes has been calculated from the intensities in the French seismic catalogue (www.Sisfrance.fr using several relations published in the literature (Grüntal & Walström 2012, Bakun & Sotti 2006, Scotti et al 1999, Levret et al 1994).

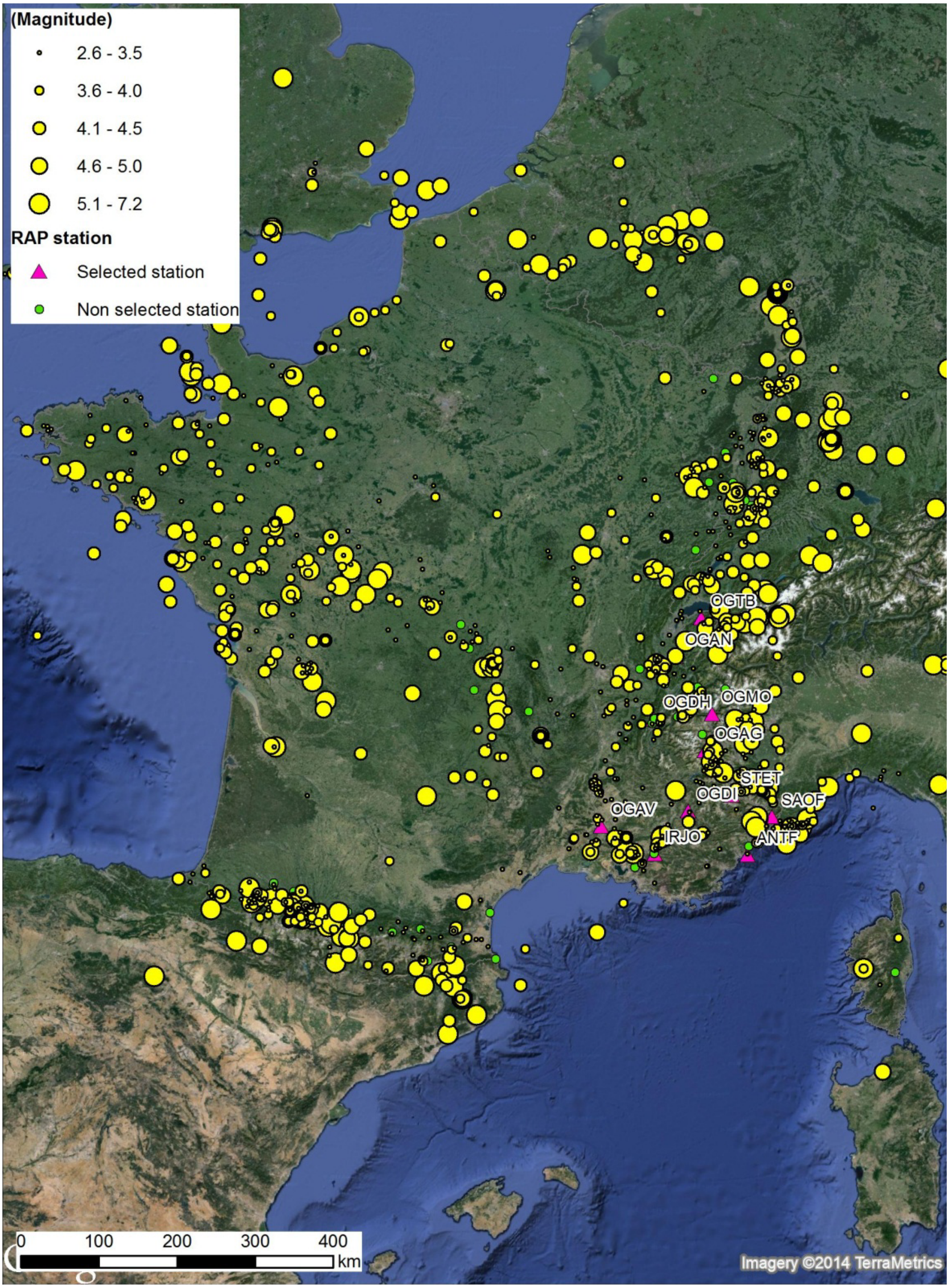


Figure 2. Seismic stations of the French seismic network, RAP (green dots) and earthquakes included in the historical REX (yellow dots). The pink triangles correspond to the selected RAP stations in the SIGMA region

Of course, the historical REX would be different if the synthetic PGAs are calculated using magnitudes or epicentral intensities. Moreover, if the intensities are used, the synthetic records will depend on the intensity relationship and on the punctual intensity-PGA relationship. For the same historic database and the same set of seismic stations, the REX can, therefore, be different. The generation of the synthetic REX would imply the consideration of epistemic uncertainty. The treatment of this epistemic uncertainty was not the main purpose of the analysis, which focuses on the feasibility of the Bayesian update. For a practical application, the user will be free to develop its own REX, choosing a threshold of acceleration, selecting sites, selecting the intensity attenuation relations, intensity-PGA relations, etc. The software capabilities are detailed in annex 1.

6. APPLICATION OF THE BAYESIAN UPDATING OF A PSHA IN THE SOUTH-EAST OF FRANCE

To test the application of the Bayesian update to the seismic hazard and to assess its relevance, we performed a series of sensitivity tests to analyze the effects of the different input data in the updating process. In the following chapters, we analyze the effect of the correlation among stations, the effect of the duration of the observation period in the updating process, the effect of the selection of a single site or a set of sites, the effect of the acceleration threshold and the effect of the use of instrumental and historical data.

To perform these tests, we used the simplified logic tree composed of 24 branches (see chapter 4).

The interpretation of the test is performed using 2 main graphics:

- The comparison between the REX and the exceedance rates at the selected stations (i.e. Figure 6). The exceedance rates at the selected stations are shown for a large range of accelerations. They are obtained as follows: (i) multiplying the seismic hazard curve of each station by the number of years of observation and (ii) adding the results of each station.
- The pdf file generated automatically by *Bayac14* (i.e. Figure 3). It shows the main input data used and the results of the updating process. The description and interpretation of the different plots and numerical information is described in annex 1.

6.1 IMPACT OF THE PERIOD OF OBSERVATION

6.1.1 Test 1: REX synthetic, PGA level=10 cm/s^2 and complete observation period

The objective of this test is to analyze the influence of the period of observation considered in the updating methodology. For example, it is interesting to know if the updating method considers equivalent (same posterior results) 2 different cases with the same *annual* exceedance rate of a fixed acceleration level but with different observation periods. To perform this test, we carried out 2 updating tests:

- In the first case we used the period of observation associated to the one station (11.69 years of working period). We compared the synthetic REX (0.1169 exceedances of 10 cm/s^2) with the exceedance rates predicted by the 24 models during 11.69 years (Test 1a, Figure 3).
- In the second case we assumed only 1 year of observation associated to the same station (i.e SAOF). We compared the supposed "*equivalent*" REX, it means keeping the same annual exceedance rate (0.1169/11.69=0.01 exceedances of 10 cm/s^2) with the annual exceedance rates predicted by the 24 models (Test 1b, Figure 4).

The results show that larger the period of observation, higher the effect of the updating method.

In the first case, even if the period of observation is short (11.69 years), the updating process is able to change the weights of the 24 branches of the logic tree slightly. The weights of the 24 branches of the logic tree are ranging from 0.038 to 0.046 depending on the branch instead of the *prior* 1/24 equivalent weight.

In the second case, using only a period of observation of 1 year and keeping the same annual exceedance rate, the effect of the updating process is negligible.

Other similar examples performed (see test 4) show that if the period of observation is short and the number of branches of the logic tree is important, the updating method doesn't modify the weights. The weights of the branches of the logic tree remain almost equivalent even if the REX is very different from the predicted results (Figure 4).

UPDATE METHOD

TEST NAME : Test 1a

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **10.0**

REX (Exceedance number) : **0.116900**

Test properties

AL: SIGMA

REX:Synthetic

Per.Obs. 11.69 year

Source directory : C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs

Sites - (1)

SAOF

Main values

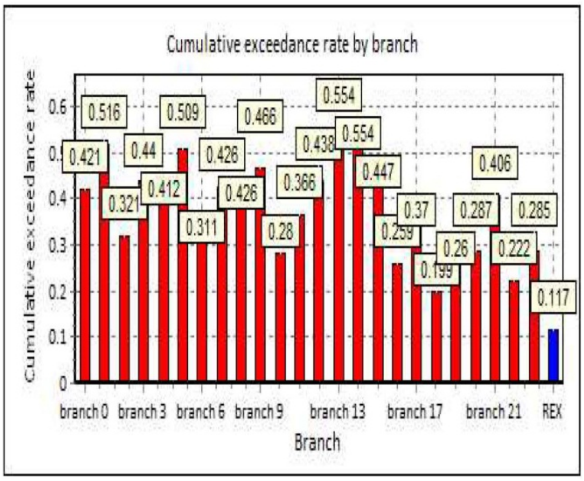
Mean exceedance rate a priori : **0.3823**

Updated rate : **0.3755**

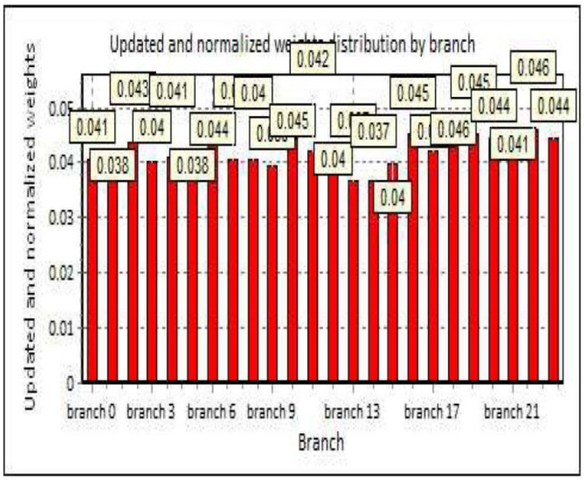
Std deviation of exceedance rate a priori : **0.1033**

Updated std dev. : **0.1010**

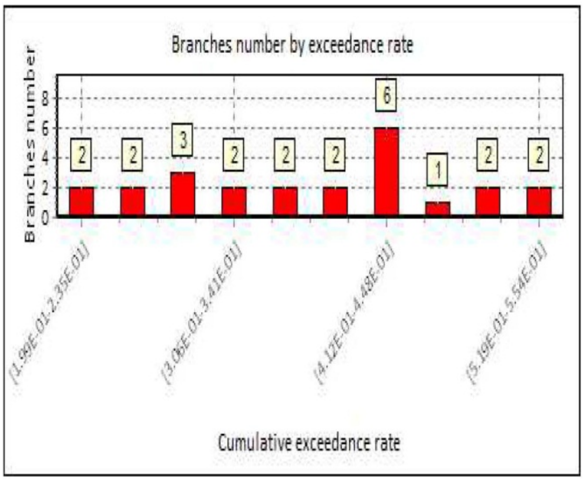
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

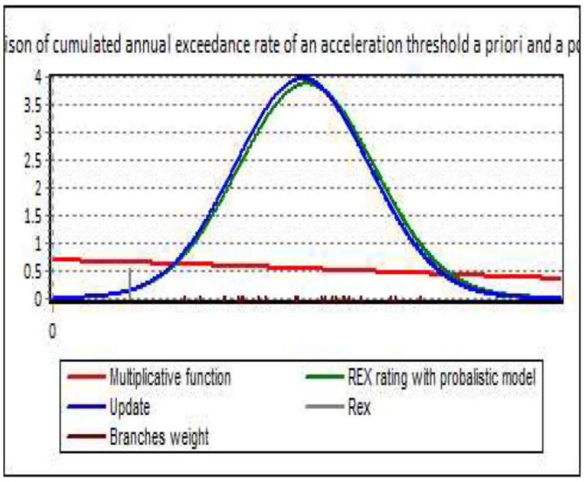


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Figure 3. Test 1a. Updating of the seismic hazard considering the real period of observation. SAOF.

UPDATE METHOD

TEST NAME : Test 1b

GEOTER

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **10.0**

REX (Exceedance number) : **0.010000**

Test properties

AL: SIGMA

REX:Synthetic

Per.Obs. 1 year

Source directory : *C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs*

Sites - (1)

SAOF

Main values

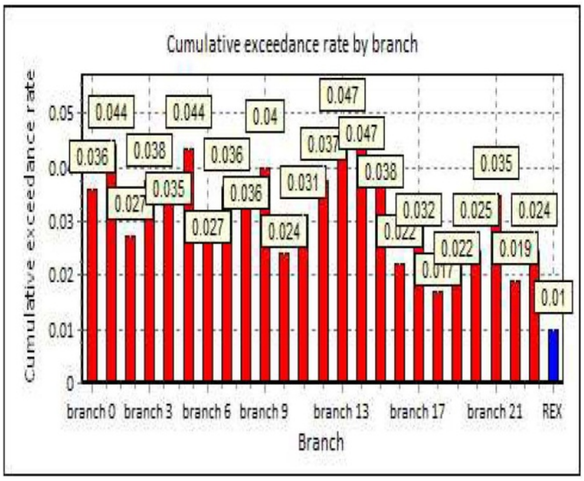
Mean exceedance rate a priori : **0.0327**

Updated rate : **0.0327**

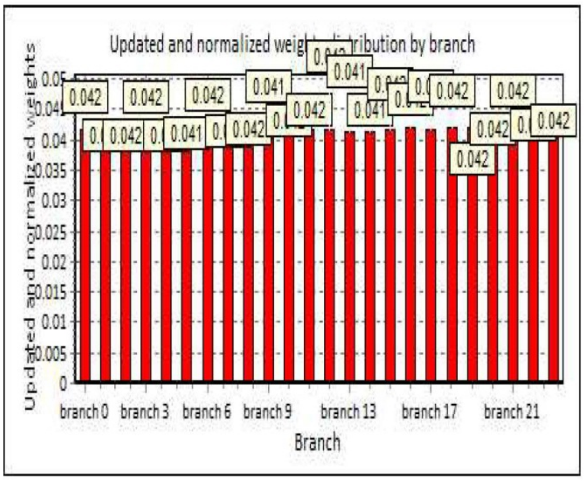
Std deviation of exceedance rate a priori : **0.0088**

Updated std dev. : **0.0087**

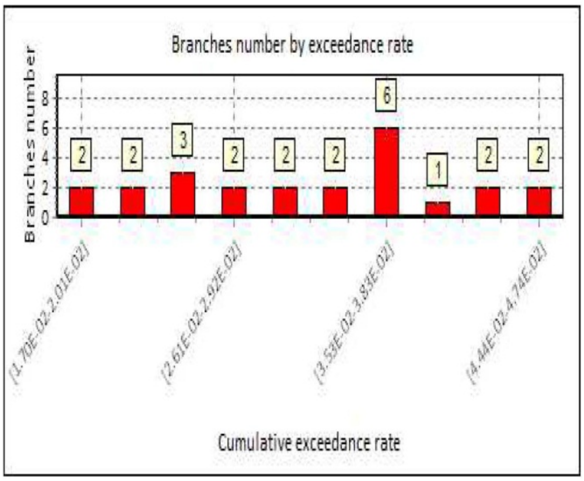
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

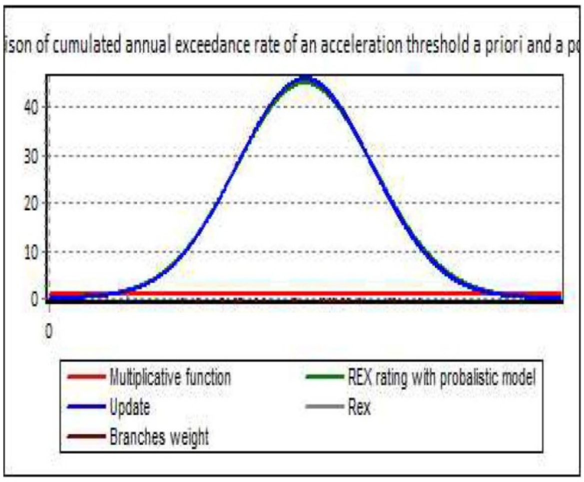


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Figure 4. Test 1b. Updating of the seismic hazard considering 1 year period of observation (annual rate) and an extended logic tree. SAOF

6.2 EFFECT OF K PARAMETER (CORRELATION BETWEEN STATIONS)

6.2.1 Test 2: REX Synthetic, PGA level=10 cm/s^2 and complete observation period

As it has been described previously in the report (chapter 3) the K parameter is a measure of the correlation among stations. If the stations are uncorrelated, an earthquake is only recorded at one station. Then, K=1 and the binomial negative distribution becomes a Poisson distribution.

If an earthquake is recorded at several stations and the acceleration threshold used in the updating is exceeded at 2 stations, there is a correlation between the 2 stations. This correlation is taken into account with the K parameter. K is the average number of sites impacted by one earthquake (Humbert & Viallet, 2008).

The objective of this test is to appreciate the effect of K parameter in the updating methodology. To carry out this test we used the same hypothesis than in the test 1a, only modifying the K parameter: 2.5 instead of 1. The results are presented in Figure 5: the updating method has a negligible effect on the weights. The prior and posterior results are equivalent. Comparing test 1a (Figure 3) and test 2 (Figure 5), we observe that the effect of the updating of the seismic hazard is more important if the K value is close to 1 (no correlation among stations). If the correlation is high, the updating is less effective.

Other tests performed corroborate this effect: higher is the k parameter, lower is the effect of the updating process.

The K parameter should be calculated for each updating case, taking into account the number of selected stations and the threshold of PGA. To determine the K value, we could use, for example, a Monte-Carlo simulation process of earthquakes in the region (i.e. using the Gutenberg-Richter distributions of seismotectonic models). Then, we could carry out a deterministic calculation (using a GMPE) of the accelerations produced at the selected stations by the simulated earthquakes. This process allows determining the number of exceedances of an acceleration level and the number of earthquakes that generated those exceedances. The K value is the ration between the number of exceedances of the acceleration threshold and the number of earthquakes that produced those exceedances. In the following tests, the K parameter was fixed equal to 1 because the stations have been selected far enough (minimum distance of 50 km between 2 stations) to avoid to consider more than one observation per earthquake.

UPDATE METHOD
TEST NAME : Test 2

GEOTER eDF

Test specifications

Files number : **24**
K value : **2.50**
Acceleration threshold (cm/s²) : **10.0**
REX (Exceedance number) : **0.116900**

Test properties
AL: SIGMA
REX:Synthetic
Per.Obs. 11.69 year

Source directory : *C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs*

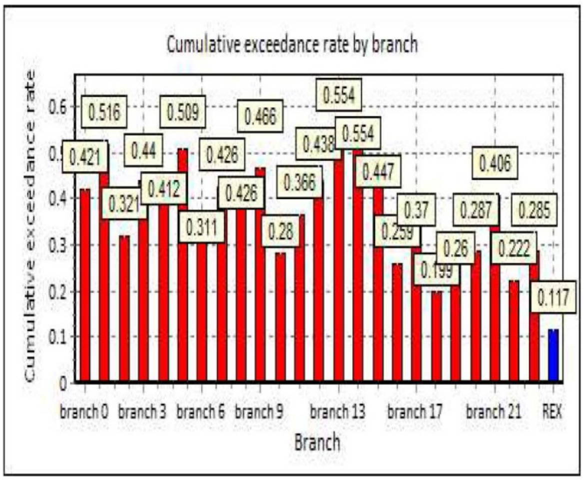
Sites - (1)

SAOF

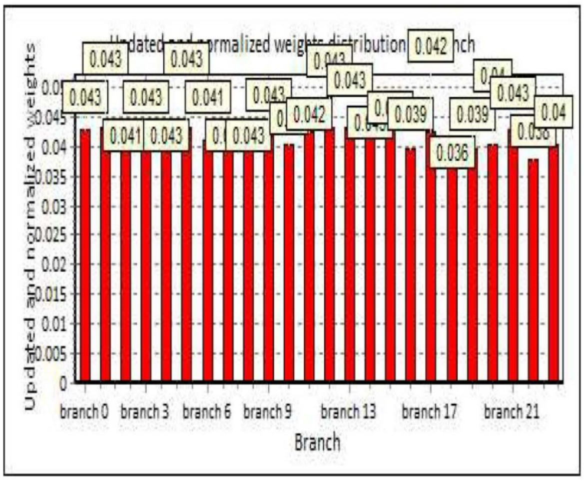
Main values

Mean exceedance rate a priori : **0.3823**
Updated rate : **0.3863**
Std deviation of exceedance rate a priori : **0.1033**
Updated std dev. : **0.1000**

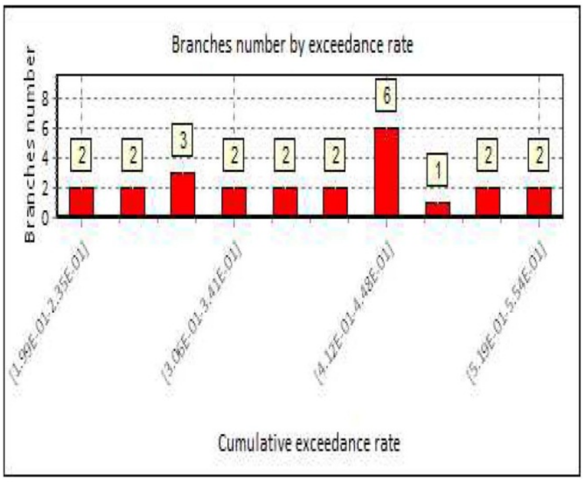
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

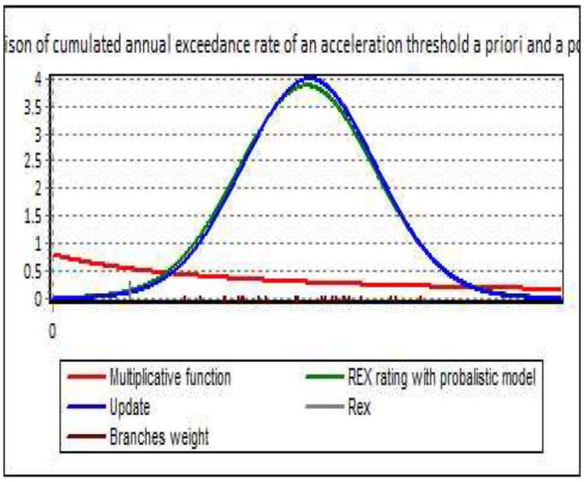


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Figure 5. Test 2. Updating of the seismic hazard considering the real period of observation. Effect of K parameter: K=2.5. SAOF

6.3 Updating of 1 site (SAOF) using data of the same site

The tests correspond to different Bayesian updating of the seismic hazard at 1 single site using data of the same site. The station chosen is SAOF because the number of observations is significant. The updating were performed using same prior logic tree and using different hypothesis (different thresholds of acceleration (PGA), different REX generated using different hypothesis). They are the following:

- Test 3: It was performed using the instrumental REX (it was 0), an acceleration threshold of 10 cm/s^2 and the observation period of SAOF station
- Text 4: It was the same than test 3 but supposing 1 year of observation instead of the complete observation period of SAOF station.
- Test 5: It was performed using the historical REX (using an intensity-PGA conversion), an acceleration threshold of 10 cm/s^2 and the historical observation period of SAOF station
- Test 6: It was the same than test 5 but supposing an acceleration threshold of 50 cm/s^2
- Test 7: It was the same than test 5 but supposing an acceleration threshold of 100 cm/s^2
- Test 8: It was performed using the historical REX (using a GMPE to define the PGA), an acceleration threshold of 10 cm/s^2 and the instrumental observation period of SAOF station.
- Test 9: It was the same than test 8 but supposing an acceleration threshold of 50 cm/s^2

6.3.1 Test 3: REX instrumental, PGA level=10 cm/s^2 and complete observation period

This test is performed using the following input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: It corresponds to the minimum acceleration level considered in the filtering process used to count the number of exceedances: 10 cm/s^2
- Minimum magnitude: The minimum magnitude considered to count the number of exceedances of the acceleration threshold is M=4.5. It corresponds to the same minimum magnitude level considered in the seismic hazard assessment defined by the logic tree used. If the probabilistic models only take into account the accelerations produced by magnitudes equal or greater than 4.5, the number of exceedances of the threshold of accelerations (REX) must be filtered using the same magnitude (4.5).
- Period of completeness of station: The period considered corresponds to the operational period of the SAOF station: 11.69 years.
- REX: It is the number of exceedances of 10 cm/s^2 produced by earthquakes with magnitude equal or greater than 4.5 during the operational period of SAOF station: 0 exceedance

The Figure 6 show the comparison between the exceedance rate predicted by the prior mean seismic hazard curve (associated to PGA) during the operational period of SAOF station (using equivalent weight per branch) and the exceedance rate predicted by the posterior mean seismic hazard curve (using the weights calculated by the updating process) during the same period. The Figure 6 includes also the cumulated exceedance rate predicted by each one of the 24 models used in this test.

The REX is equal to zero. No exceedance of 10 cm/s^2 was observed during the operational period of SAOF. However, no exceedance is also some information and the updating process changes slightly the *prior* mean seismic hazard curve. The changes are minor because the observation period is very short (only 11 years) and the REX is 0. With these conditions, the updating process doesn't have enough information to change significantly the weights of the seismic hazard curves and, therefore, the *prior* and *posterior* results are similar. The updating process is not effective when the information is scarce or limited.

The Table 1 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard.

As it was shown also in Figure 6, the updating process doesn't change significantly the seismic hazard in SAOF station. The exceedance rate of 10 cm/s^2 in SAOF station predicted by the logic tree a priori (0.38) and a posterior (0.37) is almost equivalent (Figure 7).

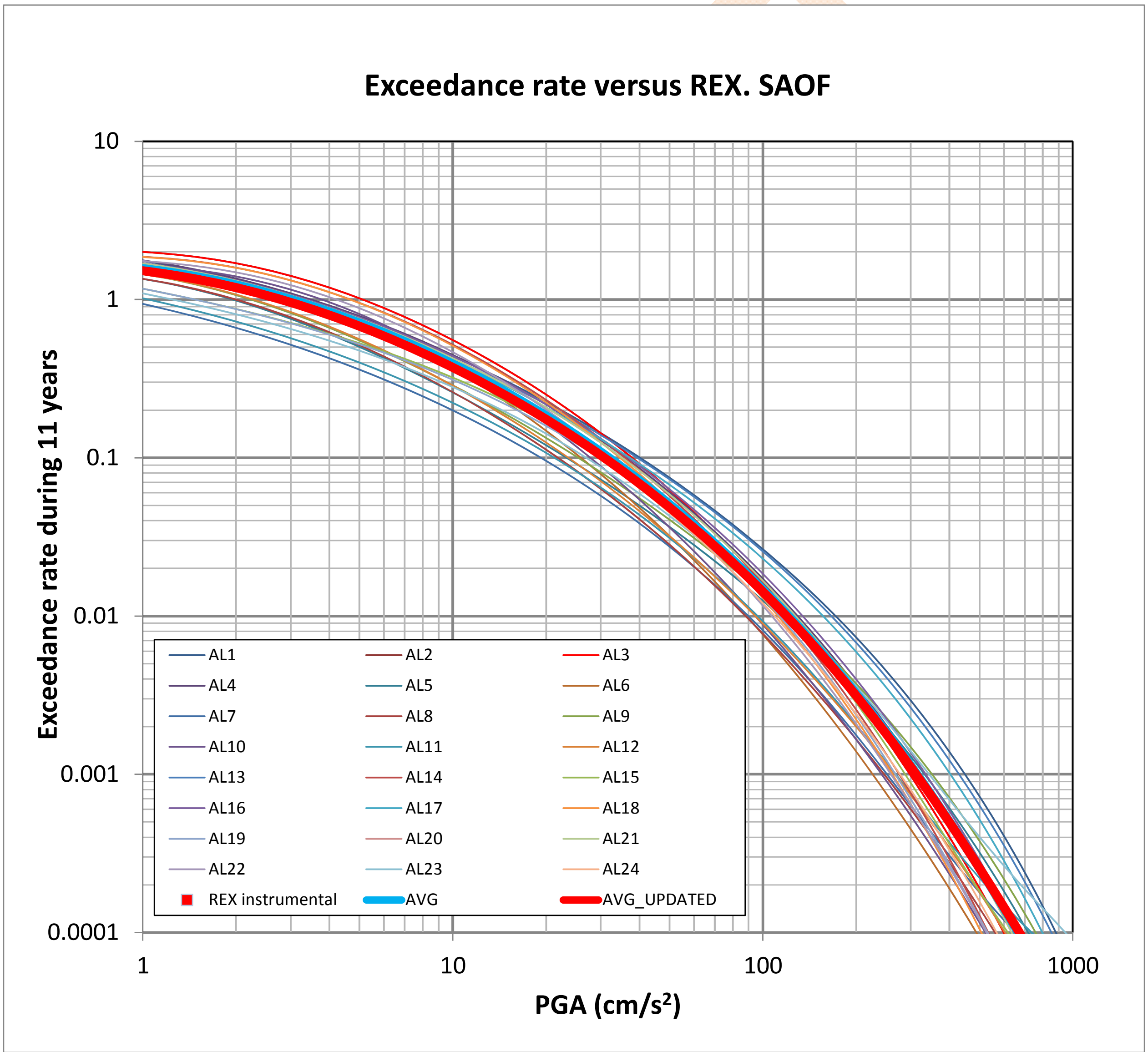


Figure 6. Test 3. Comparison ef exceedance rate during the working period of the station and the instrumental REX. SAOF.

PGA (cm/s^2)	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
Before update (Wi=1/N)	27	75	109	226	295
After update	27	74	108	225	294

Table 1. Comparison of mean PGA at different return periods, before and after the update of seismic hazard. Test 3.

UPDATE METHOD

TEST NAME : Test 3

GEOTER edf

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **10.0**

REX (Exceedance number) : **0**

Test properties

AL: SIGMA
REX:Instrumental
Per.Obs. 11.69 year
M>=4.5
PGA>=10 cm/s2

Source directory : *C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs*

Sites - (1)

SAOF

Main values

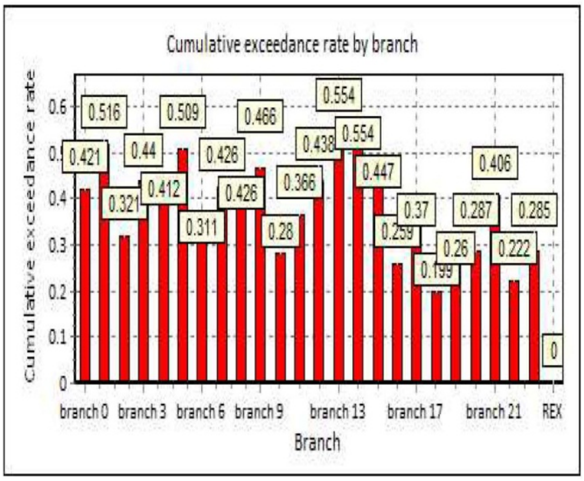
Mean exceedance rate a priori : **0.3823**

Std deviation of exceedance rate a priori : **0.1033**

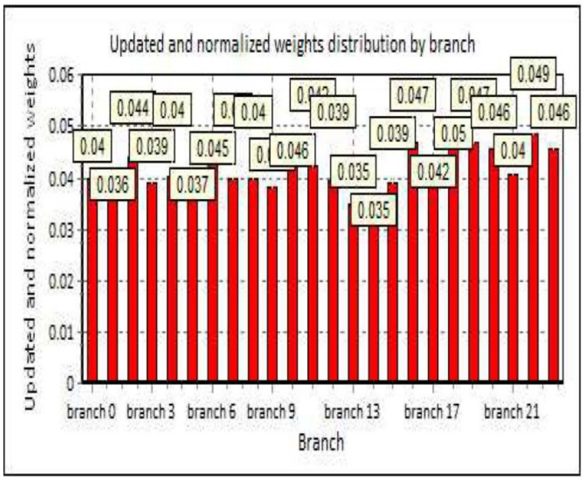
Updated rate : **0.3721**

Updated std dev. : **0.1009**

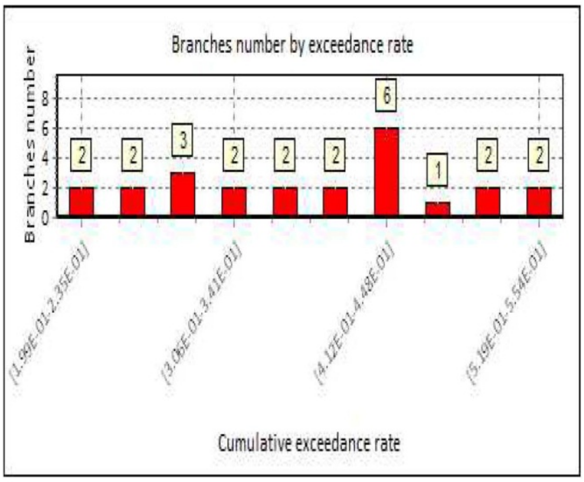
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

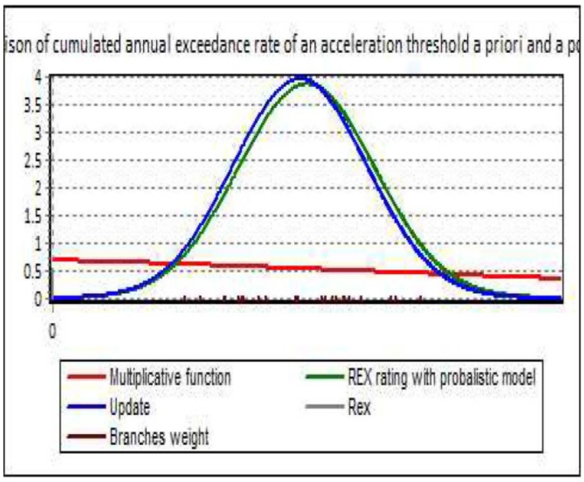


Figure 7. Test 3. Updating of the seismic hazard considering REX instrumental, PGA level=10 cm/s2 and complete observation period. SAOF

6.3.2 Test 4: REX instrumental, PGA level=10 cm/s^2 and annual observation period

This test was performed using the following input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 10 cm/s^2
- Minimum magnitude: 4.5.
- Period of completeness of station: 1 year.
- REX: 0 (considering the instrumental period of SAOF)

The Table 2 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard.

PGA (cm/s^2)	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
Before update (Wi=1/N)	27	75	109	226	295
After update	27	75	109	226	295

Table 2. Comparison of mean PGA at different return periods, before and after the update of seismic hazard. Test 4.

The table 2 and the summary sheet created by *Bayac14* (Figure 8) shows that the updating process has no effect, mainly due to the short period of observation used (1 year). This test was mainly performed to confirm that the use of a very short period of observation (and therefore, a REX near to zero) implies that the Bayesian updating process doesn't change the *prior* results.

UPDATE METHOD

TEST NAME : Test 4

GEOTER edF

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **10.0**

REX (Exceedance number) : **0.000000**

Test properties

AL: SIGMA
REX:Instrumental
Per.Obs. 1 year
M>=4.5
PGA>=10 cm/s2

Source directory : *C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs*

Sites - (1)

SAOF

Main values

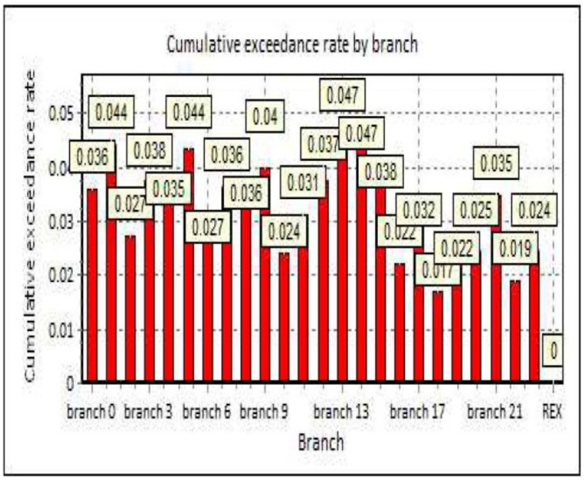
Mean exceedance rate a priori : **0.0327**

Updated rate : **0.0326**

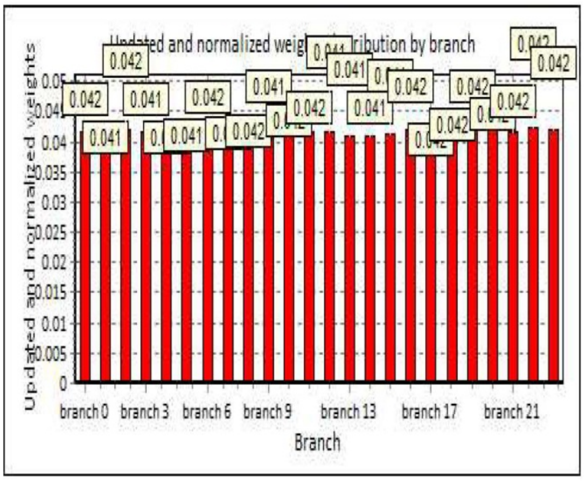
Std deviation of exceedance rate a priori : **0.0088**

Updated std dev. : **0.0087**

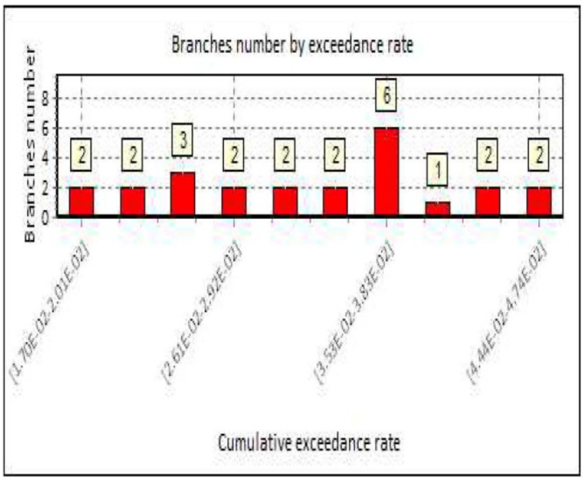
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

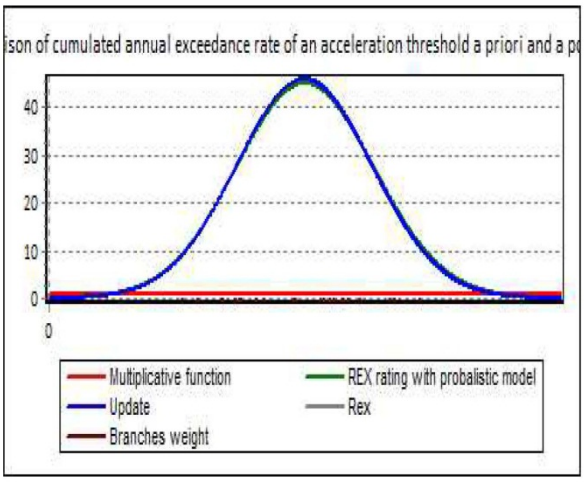


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Figure 8. Test 4. Updating of the seismic hazard considering REX instrumental, PGA level=10 cm/s2 and annual observation period. SAOF.

6.3.3 Test 5: REX historical, PGA level=10 cm/s^2 and Intensity-PGA relation

The objective of this test is to enlarge the period of observation at the site. We consider the historical REX, with a larger observation period than the instrumental REX.

This test was performed using the following input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 10 cm/s^2
- Minimum magnitude: 4.5.
- Period of completeness of station: 82 years (only the events occurred from 1880 to 1962 were considered).
- REX: There are 2 exceedances of 10 cm/s^2, from 1880 to 1962 (selected as the SAOF complete period because it is the period of completeness of intensity V). The REX can be estimated using 2 methodologies and using many relations. However, when we are using low acceleration thresholds (i.e. 10 cm/s^2) the majority of the relations to convert intensities into PGAs (i.e. PS92, Gomez & Capera, 2007, Panza et al. 1997, etc.) cannot be used because they are not applicable to intensities lower than 4 or 5 (using these relations, intensity 3 could lead to PGA higher than 10 cm/s^2). The choice adopted consists in using the Mezcua et al. (2013) method, combining the relation of Mezcua et al. (2004) to convert magnitudes into site intensities and the relation of Atkinson and kaka (2007) that can be used to convert intensity into PGA from intensity 2 to 9. Using this method the number of exceedances of 10 cm/s2, from 1880 to 1962, due to earthquakes with Mw>=4.5 is 2. The period of completeness associated to 10 cm/s^2 is subject of controversy and, in the bibliography, there are complex methods to define them (Selva & Sandri, 2013 and Mezcua et al, 2013). However, the aim of this study being to analyze the behavior of the Bayesian methodology under different hypothesis, we excluded from the analyses the effect of completeness periods or site effects that may be included in the REX.

The Figure 9 shows the comparison between the exceedance rate predicted by the prior mean seismic hazard curve (associated to PGA) during the operational period of SAOF station (using equivalent weight per branch) and the exceedance rate predicted by the posterior mean seismic hazard curve (using the weights calculated by the updating process) during the same period.

The historical REX is equal to 2 (biggest red dot in Figure 9). Only for information purposes, the Figure 9 shows also the REX (annual rate * 82 years of observation) calculated using a threshold of acceleration of 50 cm/s^2 and 100 cm/s^2 (these PGA level will be used in test 6 and 7).

In this case, the *posterior* mean seismic hazard curve is closer to the REX, at PGAs around 10 cm/s2 (the threshold of acceleration used for this test). Nevertheless, we note that this behavior is not valid for all range of accelerations. For PGAs greater than 100 cm/s2, the prior and posterior seismic hazard curves are similar. The effects of the updating process seem to be not equivalent for all range of accelerations. However, this fact should be considered as normal, because the slopes of the seismic hazard curves are not constant.

The Table 3 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard.

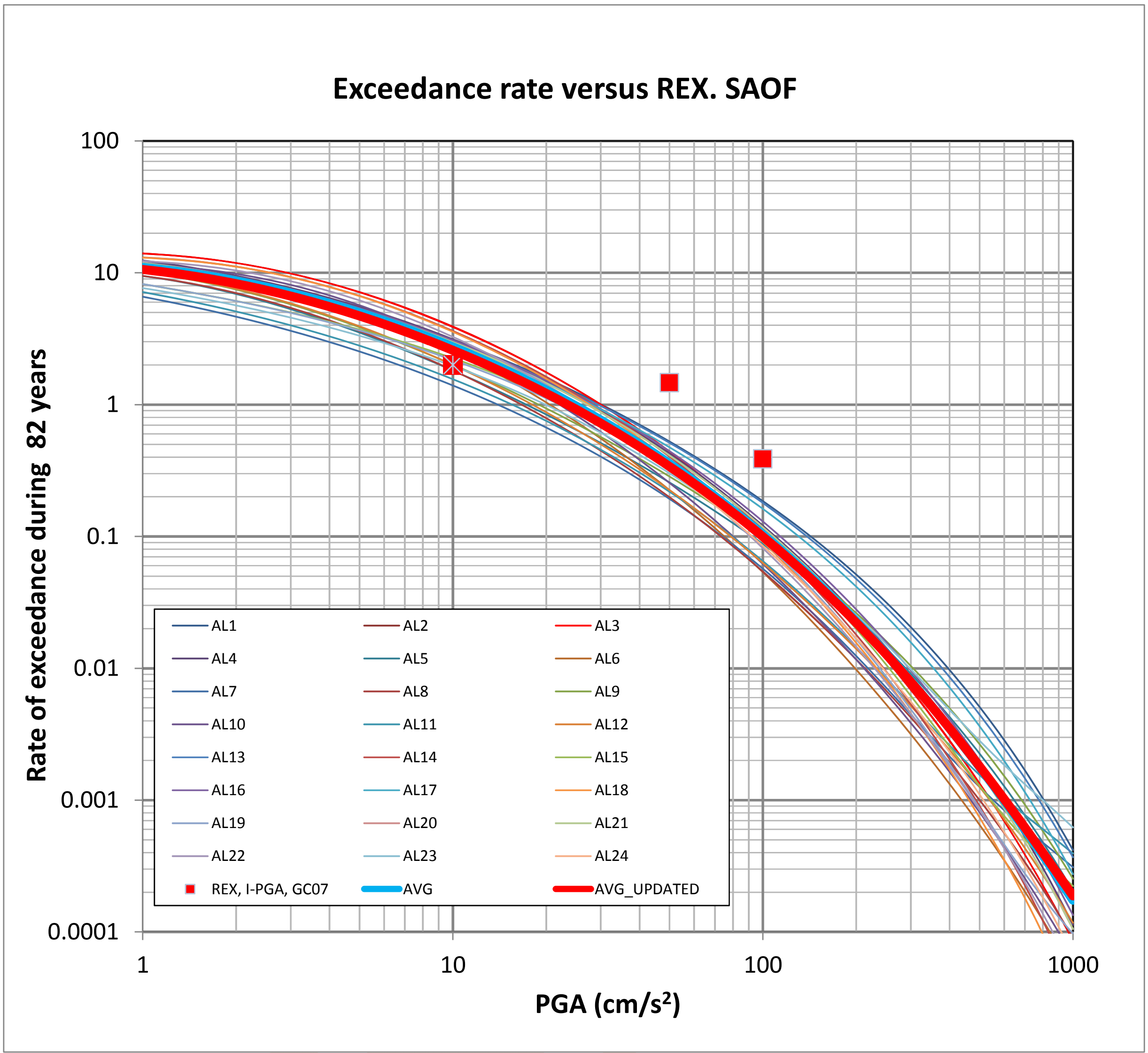


Figure 9.Test 5. Comparison of exceedance rate during the working period of the station and the historical REX. SAOF.

PGA (cm/s^2)	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
Before update (Wi=1/N)	27	75	109	226	295
After update	27	74	108	225	296

Table 3. Comparison of mean PGA at different return periods, before and after the update of seismic hazard. Test 5.

UPDATE METHOD

TEST NAME : Test 5

GEOTER EDF

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **10.0**

REX (Exceedance number) : **2.000000**

Test properties

REX_HISTO
M>=4.5
PGA>=10
Date>1880
Per.fonc: 82
Mez04 + Atkk07

Source directory : *C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs*

Sites - (1)

SAOF

Main values

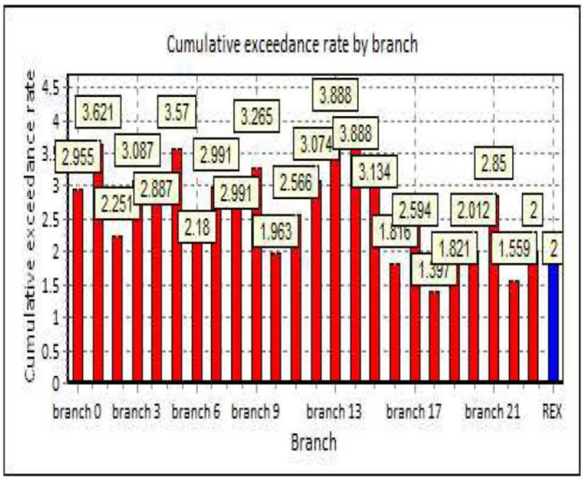
Mean exceedance rate a priori : **2.6817**

Updated rate : **2.5848**

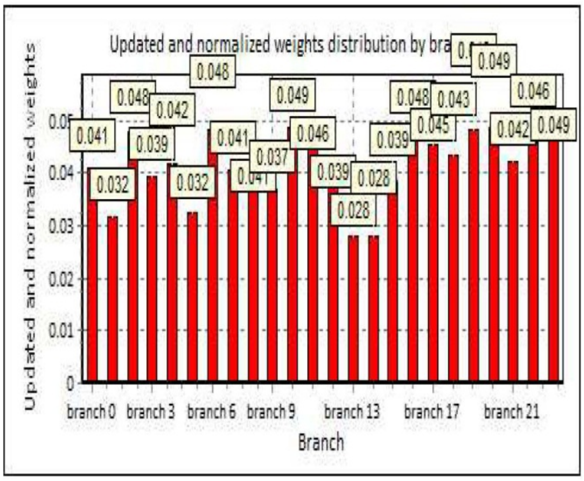
Std deviation of exceedance rate a priori : **0.7244**

Updated std dev. : **0.6826**

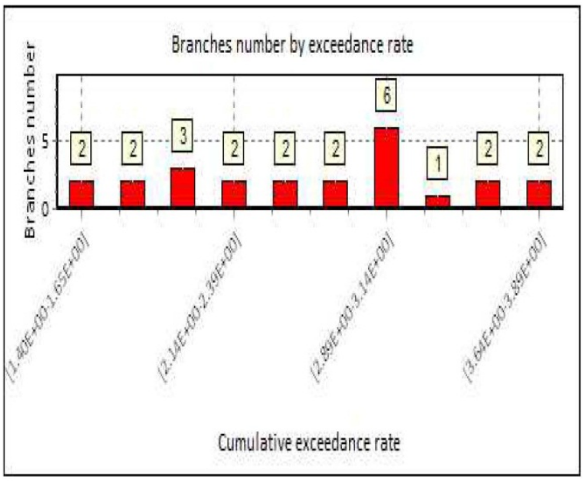
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

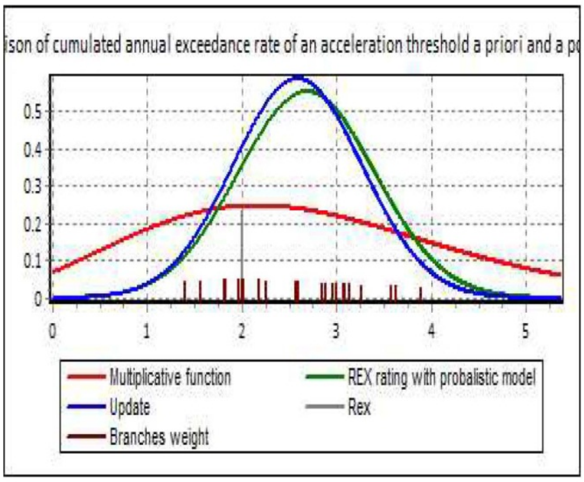


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Figure 10. Test 5. Updating of the seismic hazard considering REX historical, PGA level=10 cm/s2 and Intensity-PGA relation. SAOF.

6.3.4 Test 6: REX historical, PGA level=50 cm/s^2 and Intensity-PGA relation

This is a case where the REX (in this case, estimated using intensity-PGA relations) is higher than the predictions, for all 24 branches of the logic tree.

This test was performed using the following input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 50 cm/s^2
- Minimum magnitude: 4.5.
- Period of completeness of station: 112 years (only the events occurred from 1850 to 1962 were considered).
- REX: The REX (number of exceedances of 50 cm/s^2 during 112 years, from 1850 to 1962) was fixed to 2 (considering the historical period of observation of SAOF, from 1850 to 1962 and using the intensity attenuation law developed for Alpine region in France (report GTR/EDF/0707-396) to find the site intensity at SAOF site and the PS92 equation to convert the intensities into PGA)

The Figure 11 shows, again, the comparison between the exceedance rate predicted by the mean seismic hazard curve (associated to PGA) *a priori* during the operational period of SAOF station (annual rate * 112 years of observation) and the exceedance rate predicted by the mean seismic hazard curve *a posteriori* (using the weights calculated by the updating process) during the same period.

The historical REX is equal to 2 (biggest red dot in Figure 11). Only for information purposes, the Figure 11 shows also the REX (number of exceedances during 112 years using a threshold of acceleration of 10 cm/s^2 and 100 cm/s^2 (PGA levels used in test 5 and 7).

It means that we estimated that 2 exceedances of 50 cm/s2 were observed during the complete period associated to 50 cm/s^2 (estimated to 112 years) in SAOF station.

The Table 4 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard, in SAOF station.

The prior mean exceedance rate is 0.47 and the posterior mean exceedance rate is 0.53 (Figure 11 and Figure 12). The modification of the weights of the probabilistic models (Figure 12) increases the seismic hazard at all return periods (Table 4). This example shows that the updating method tends to fit the seismic hazard predictions to the observations. If the observations are higher than the predictions (as in this test), the effect of the updating process is to increase the mean seismic hazard.

This test shows an example where the REX is very much higher than the predicted values, for all branches of the logic tree. Anyone of the branches of the logic tree is able to predict, even approximately, the observed REX. In this case, the updating process gives a higher weight to those probabilistic models that predicts higher occurrence rates for 50 cm/s^2.

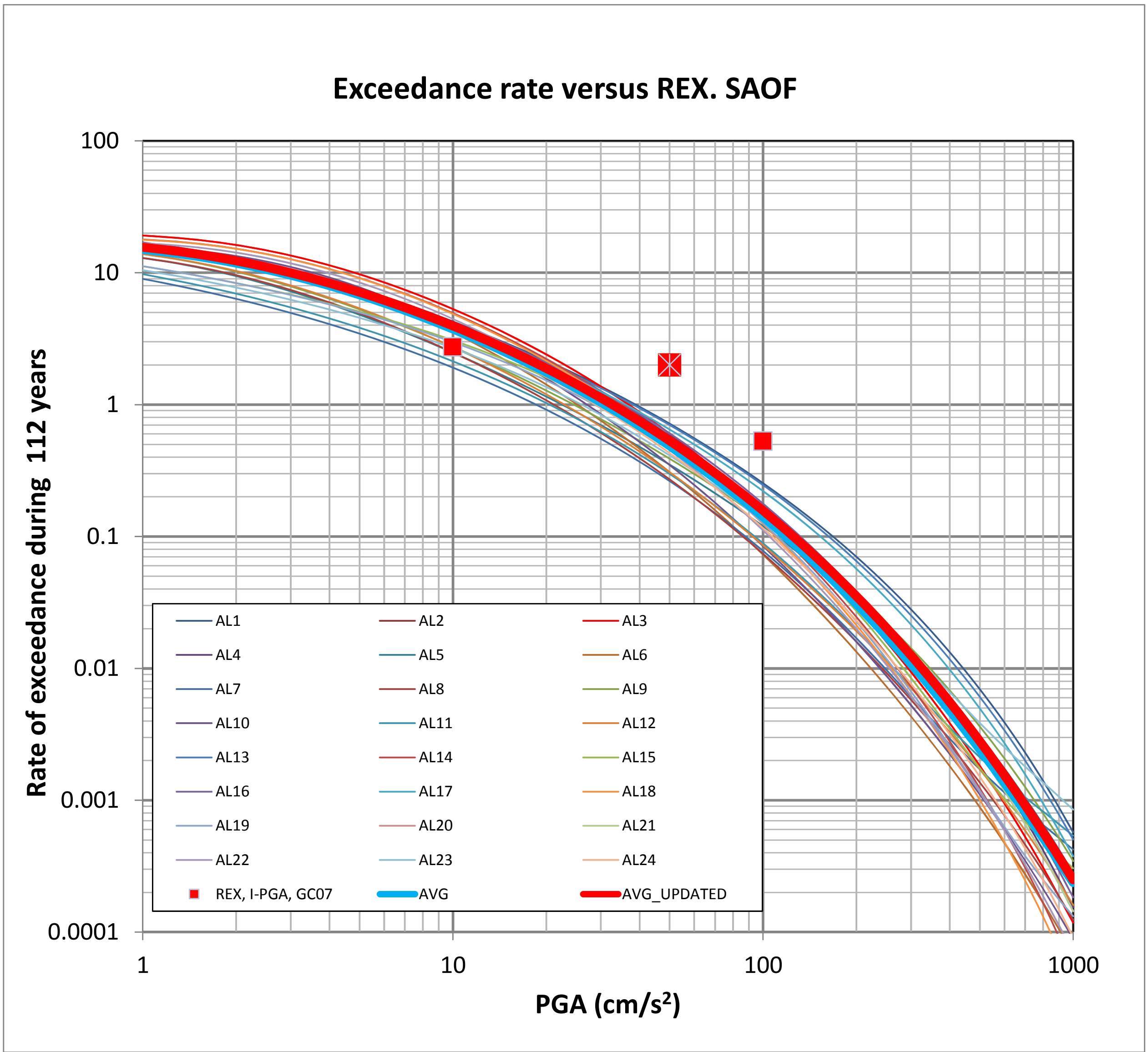


Figure 11. Test 6. Comparison of exceedance rate during the working period of the station and the historical REX. SAOF.

PGA (cm/s^2)	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
Before update (Wi=1/N)	27	75	109	226	295
After update	30	80	117	240	312

Table 4. Comparison of mean PGA at different return periods, before and after the update of seismic hazard. Test 6.

UPDATE METHOD

TEST NAME : Test 6

GEOTER EDF

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **50.0**

REX (Exceedance number) : **2.000000**

Test properties

REX_HISTO
M>=4.5
PGA>=50
Date>1850
Per.fonc: 112
Int (Alpes, Provence) + PS92

Source directory : *C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs*

Sites - (1)

SAOF

Main values

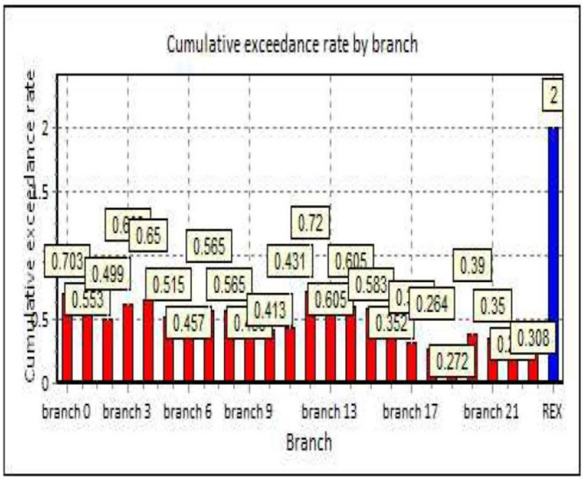
Mean exceedance rate a priori : **0.4780**

Updated rate : **0.5342**

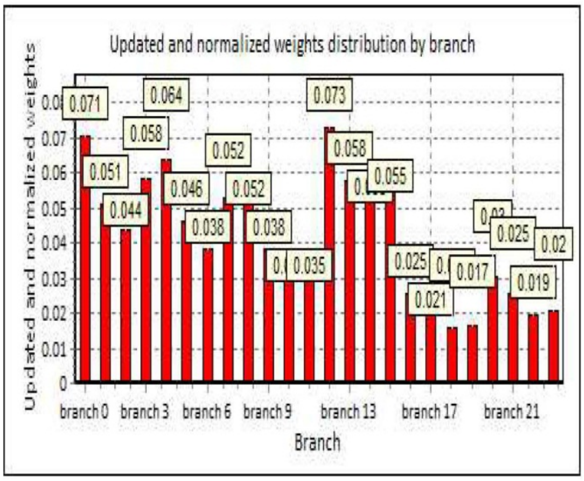
Std deviation of exceedance rate a priori : **0.1392**

Updated std dev. : **0.1242**

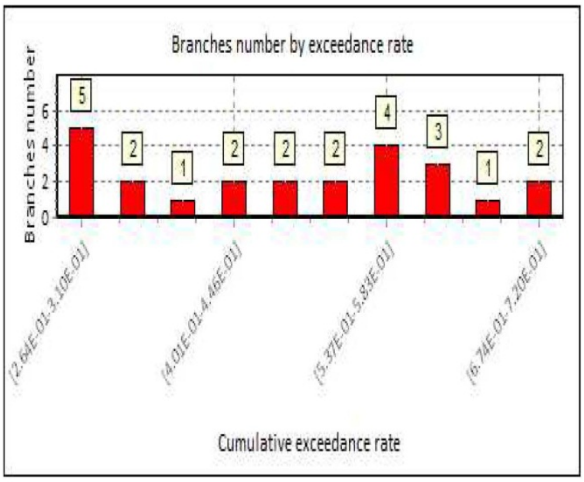
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

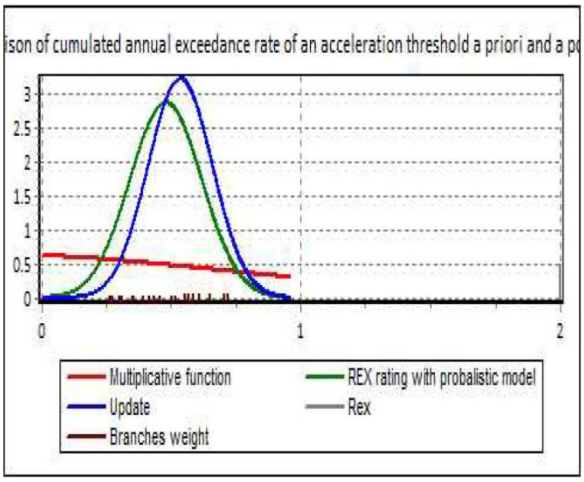


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Figure 12.Test 6. Updating of the seismic hazard considering REX historical, PGA level=50 cm/s2 and Intensity-PGA relation. SAOF

6.3.5 Test 7: REX historical, PGA level=100 cm/s^2 and Intensity-PGA relation

This is another case where the REX (in this case, estimated using intensity-PGA relations) is higher than the predictions, for all 24 branches of the logic tree.

This test was performed using the following input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 100 cm/s^2
- Minimum magnitude: 4.5.
- Period of completeness of station: 212 years (only the events occurred from 1750 to 1962 were considered).
- REX: The REX (number of exceedances of 100 cm/s^2 during 212 years, from 1750 to 1962) was fixed to 1 using the intensity attenuation law developed for Alpine region in France (report GTR/EDF/0707-396) to find the punctual intensity at SAOF site and the PS92 equation to convert the intensities into PGA.

The Figure 13 shows, again, the comparison between the exceedance rate predicted by the prior mean seismic hazard curve (associated to PGA) during the operational period of SAOF station and the exceedance rate predicted by the posterior mean seismic hazard curve (using the weights calculated by the updating process) during the same period.

The historical REX is equal to 1 (biggest red dot in Figure 13). Only for information purposes, the Figure 13 shows also the REX (number of exceedances during 112 years) using a threshold of acceleration of 10 cm/s^2 and 50 cm/s^2 (PGA levels used in test 5 and 6). It means that we estimated that 1 exceedance of 100 cm/s^2 was observed during the complete period associated to 100 cm/s^2 (estimated to 212 years) in SAOF station.

In this case, the updating method increases slightly the mean seismic hazard. The Table 4 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard, in SAOF station.

The prior mean exceedance rate is 0.26 and the posterior mean exceedance rate is 0.28 (Figure 13 and Figure 14). The modification of the weights of the probabilistic models (Figure 14) increases slightly the seismic hazard at all return periods (Table 4).

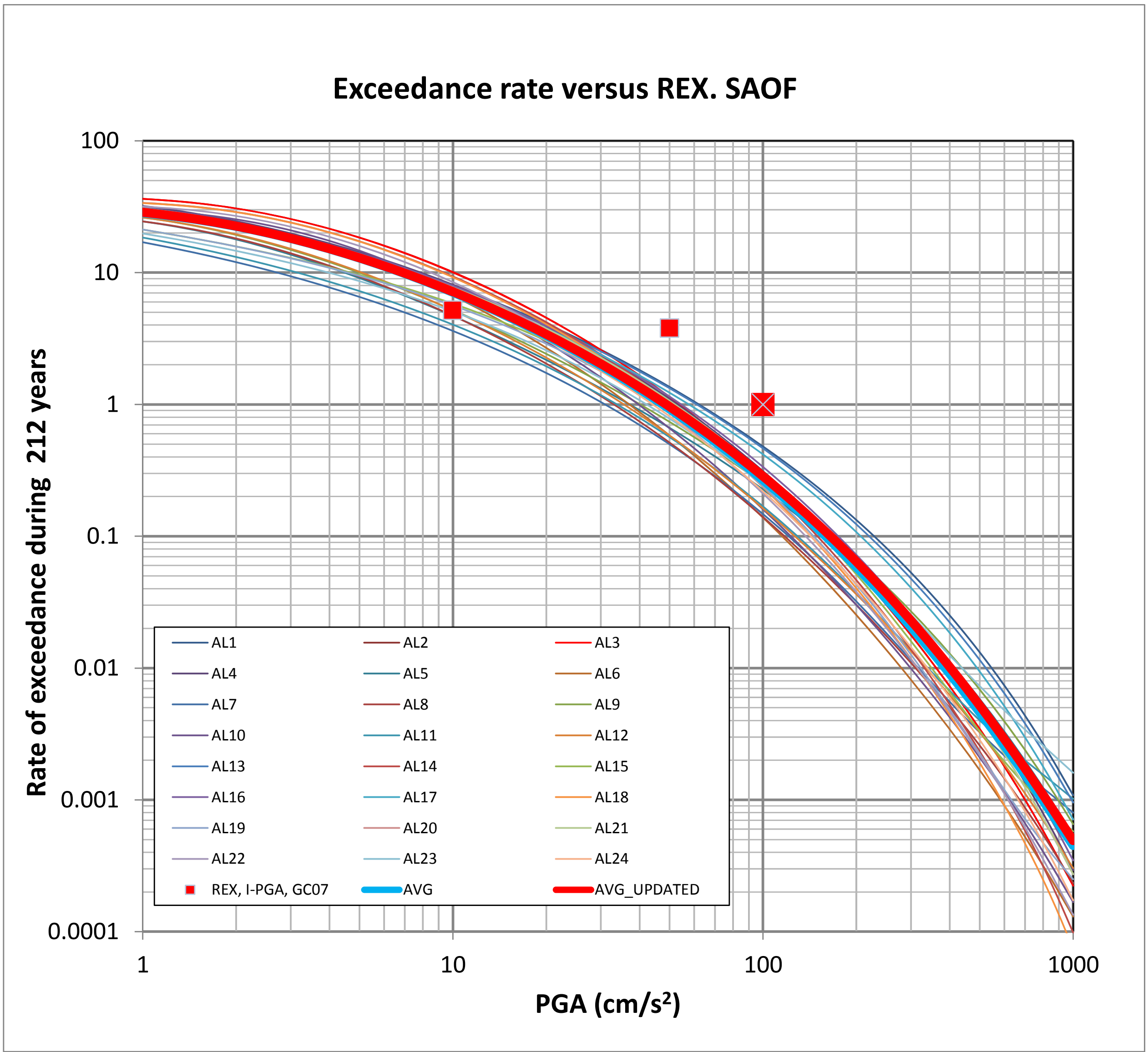


Figure 13. Test 7. Comparison of exceedance rate during the working period of the station and the historical REX. SAOF.

PGA (cm/s^2)	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
Before update (Wi=1/N)	27	75	109	226	295
After update	29	79	115	237	309

Table 5. Comparison of mean PGA at different return periods, before and after the update of seismic hazard. Test 7.

UPDATE METHOD

TEST NAME : Test 7

GEOTER edf

Test specifications

Files number : **24**	*Test properties*
K value : **1.01**	REX_HISTO
Acceleration threshold (cm/s²) : **100.0**	M>=4.5
REX (Exceedance number) : **1.000000**	PGA>=50
	Date>1850
	Per.fonc: 112
	Int (Alpes, Provence) + PS92

Source directory : *C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs*

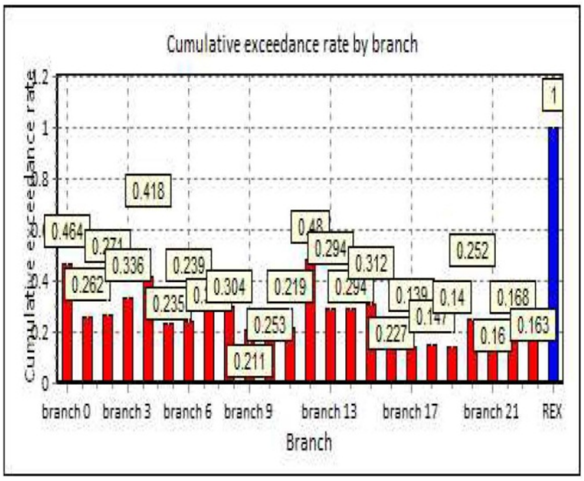
Sites - (1)

SAOF

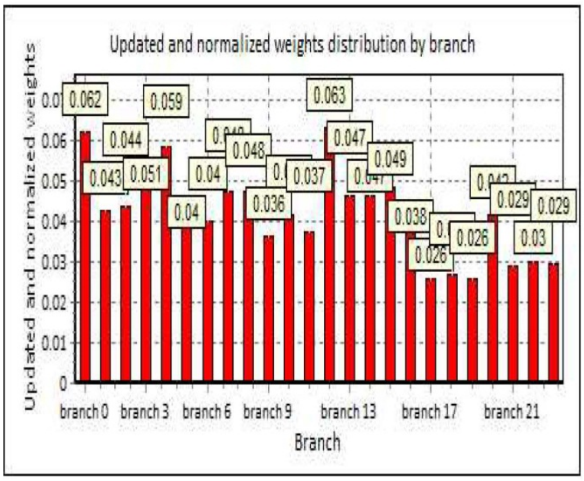
Main values

Mean exceedance rate a priori : **0.2621**	*Updated rate :* **0.2852**
Std deviation of exceedance rate a priori : **0.0946**	*Updated std dev. :* **0.0968**

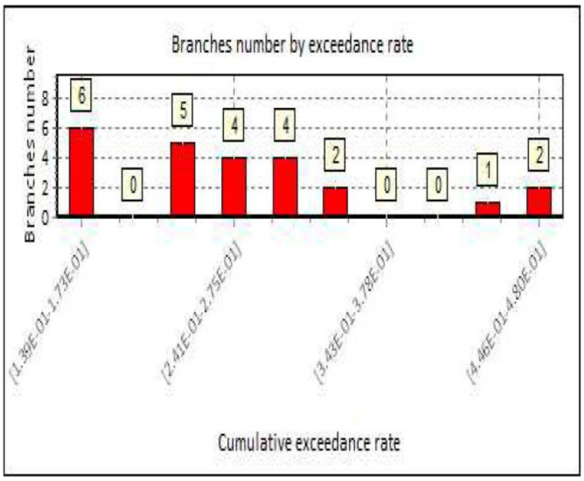
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

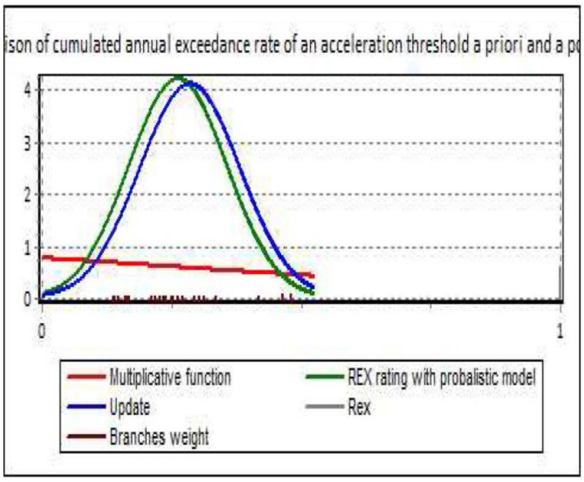


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Figure 14.Test 7. Updating of the seismic hazard considering REX historical, PGA level=50 cm/s2 and Intensity-PGA relation. SAOF

6.3.6 Test 8: REX historical, PGA level=10 cm/s^2 and Magnitude-PGA relation

The following test was performed using as input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 10 cm/s^2.
- Minimum magnitude: 4.5.
- REX: 1 (considering the historical period of SAOF, from 1880 to 1962). The acceleration values were obtained using the Drouet 2013 relation. Using this conversion, we obtained only 1 exceedance during the period considered. In previous tests, the accelerations were calculated using the linear IPE (Intensity Prediction Equations) and the PS92 conversion (to transform site intensity to PGA). In that case, 2 exceedances of 10cm/s^2 were founded. This is one example showing that differences between the estimated REX may be significant depending on the method adopted to generate the synthetic data. The definition of the REX is a key point in the updating process and should be analyzed in detail. If the GMPE of Cauzzi and Faccioli, 2008 (one of the best adapted GMPEs to the French territory, Beauval et al. 2007), is used instead of Drouet 2013, the REX obtained is also 1.
- Period of completeness of station: 82 years (from 1880 to 1962).

The Figure 15 shows the comparison between the exceedance prior and posterior rates. In this case, the historical REX using the conversion equations previously indicated (GMPE of Drouet, 2013) is equal to 1 (biggest red dot in Figure 15).

The effects of the updating method are visible. The *posterior* mean exceedance rate is situated closer to the REX and it is less penalizing than the *prior* exceedance rate for small PGA. At higher PGAs the p*rior* and *posterior* exceedance rates become almost equivalent.

The Table 6 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard, at SAOF station.

The update of the seismic hazard reduces the exceedance rate of 10 cm/s^2 during the period of observation (from 2.68 *a priori* to 2.39 *a posteriori*, Figure 15 and Figure 16). This slight reduction affects all return periods (Table 6). The weights of the *posterior* models are significantly different from the *prior* equivalent weights. However, in terms of mean peak ground acceleration, the differences *a priori* and *a posteriori* are not important. This is due to the fact that all 24 branches of the logic tree show relatively similar predictions (between 1.3 and 3.8). Therefore, the changes of weights don't affect significantly the results, mainly to moderate and high PGAs.

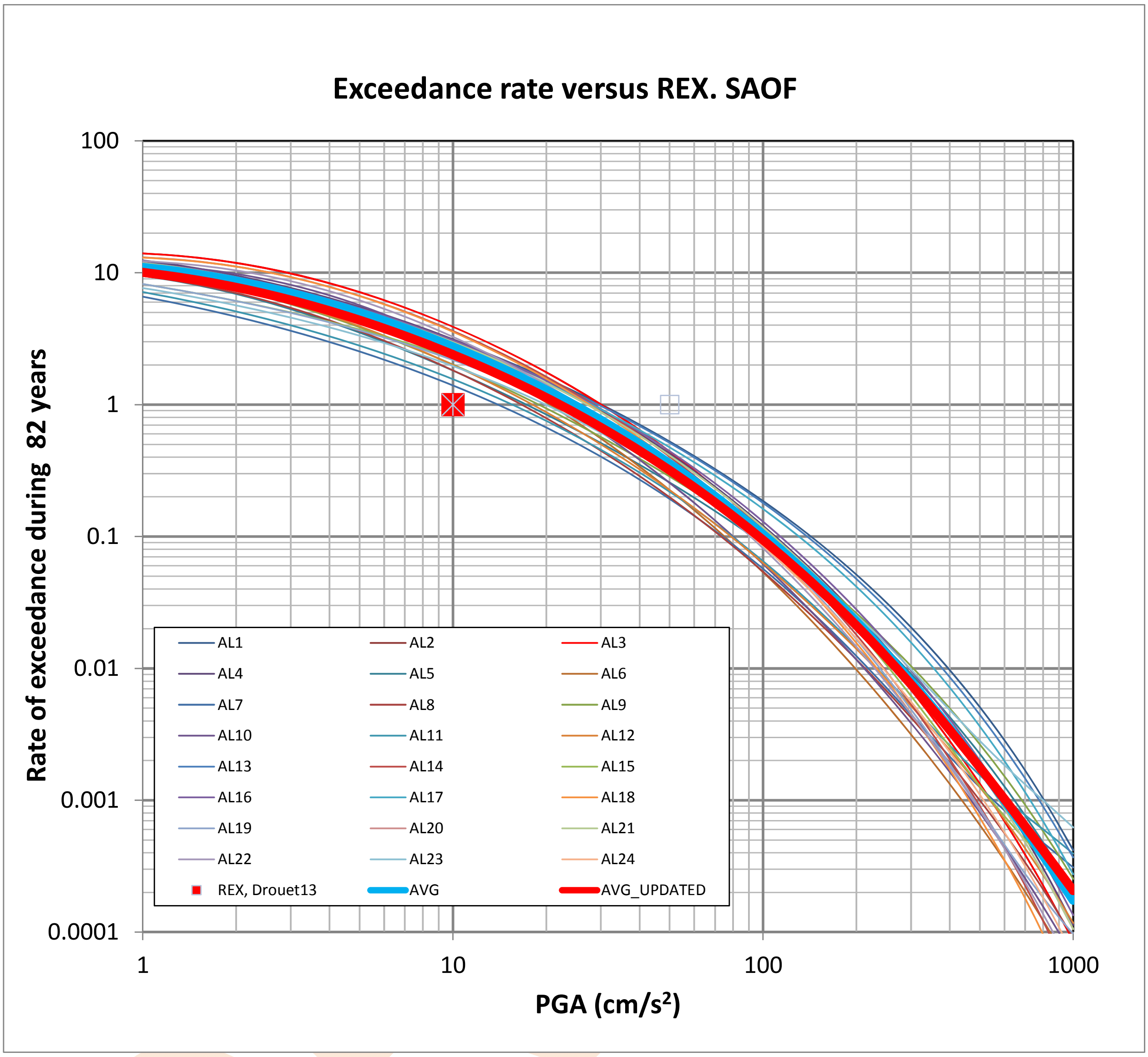


Figure 15. Test 8. Comparison of exceedance rate during the working period of the station and the historical REX. SAOF.

PGA (cm/s^2)	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
Before update (Wi=1/N)	27	75	109	226	295
After update	25	71	105	221	291

Table 6. Comparison of mean PGA at different return periods, before and after the update of seismic hazard. Test 8.

UPDATE METHOD
TEST NAME : Test 8

GEOTER | eDF

Test specifications

Files number : **24**
K value : **1.01**
Acceleration threshold (cm/s²) : **10.0**
REX (Exceedance number) : **1.000000**

Test properties
AL SIGMA
Date>1880
Obs. Per.: 82
M>=4.5

Source directory : C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs

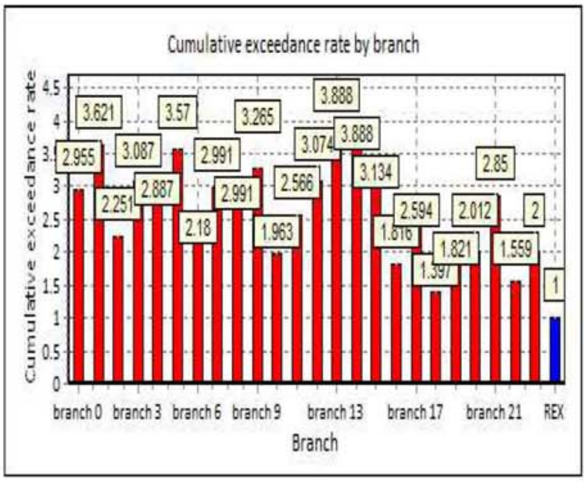
Sites - (1)

SAOF

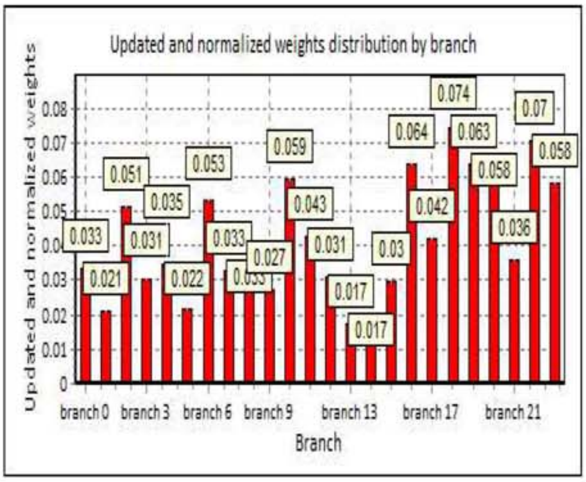
Main values

Mean exceedance rate a priori : **2.6817**
Std deviation of exceedance rate a priori : **0.7244**
Updated rate : **2.3961**
Updated std dev. : **0.6736**

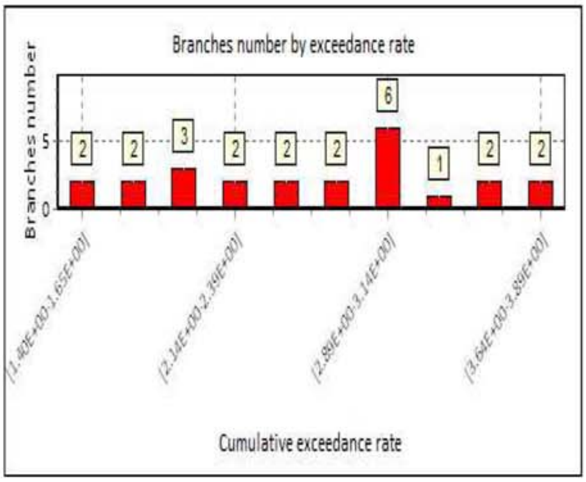
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

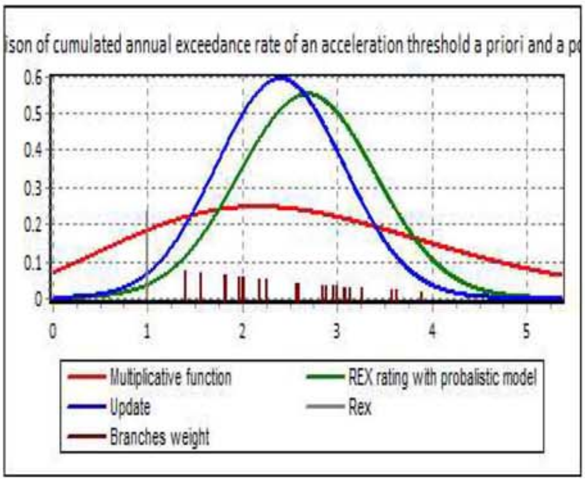


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Figure 16. Test 8. Updating of the seismic hazard considering REX historical, PGA level=10 cm/s2 and Magnitude-PGA relation. SAOF

6.3.7 Test 9: REX historical, PGA level=50 cm/s² and Magnitude -PGA relation

The following test was performed using as input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 50 cm/s^2.
- Minimum magnitude: 4.5.
- Period of completeness of station: 212 years (only the events occurred from 1750 to 1962 were considered).
- REX: 1 (considering the historical period of SAOF, from 1750 to 1962). The acceleration values were obtained using the Drouet 2013 relation. If the relation of Cauzzi and Faccioli (2008) is used, the REX is also 1. Using this conversion, we obtained only 1 exceedance during the period considered.

The Figure 17 shows the comparison between the *prior* and *posterior* exceedance rates.

The historical REX is equal to 1 (biggest red dot in Figure 17). The predictions (exceedance rates curves) and the REX have an excellent agreement.

In this case, effects of the updating method are negligible. The *posterior* mean exceedance rate and the *prior* exceedance are almost equivalent, because of the agreement between observations and predictions.

The Table 7 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard. In this case, the update of the seismic hazard considering 50 cm/s^2 leads to a very slight augmentation of the seismic hazard for all return periods (Figure 17 and Figure 18).

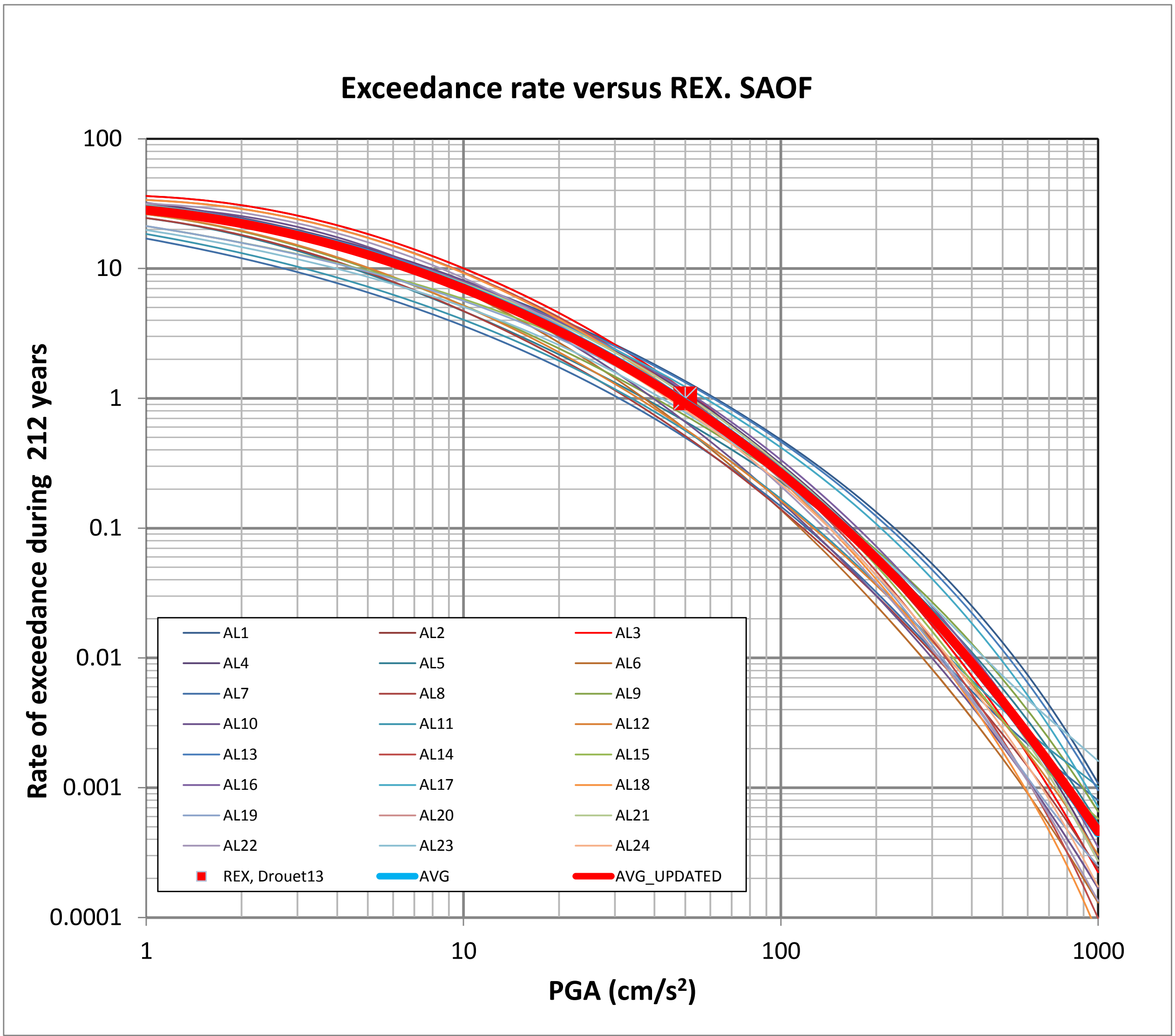


Figure 17. Test 9. Comparison of exceedance rate during the working period of the station and the historical REX. SAOF.

PGA (cm/s^2)	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
Before update (Wi=1/N)	27	75	109	226	295
After update	28	76	110	227	296

Table 7. Comparison of mean PGA at different return periods, before and after the update of seismic hazard. Test 9.

UPDATE METHOD

TEST NAME : Test 9

GEOTER eDF

Test specifications

Files number : **24**
K value : **1.01**
Acceleration threshold (cm/s²) : **50.0**
REX (Exceedance number) : **1.000000**

Test properties
AL: SIGMA
REX:1
Per. Fonc.212
M>4.5
Date>1750

Source directory : *C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs*

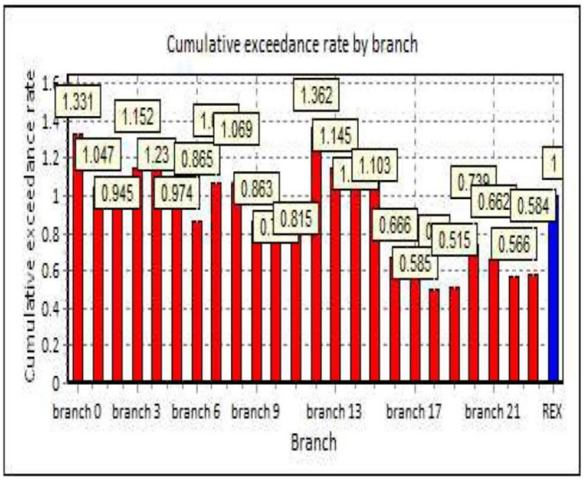
Sites - (1)

SAOF

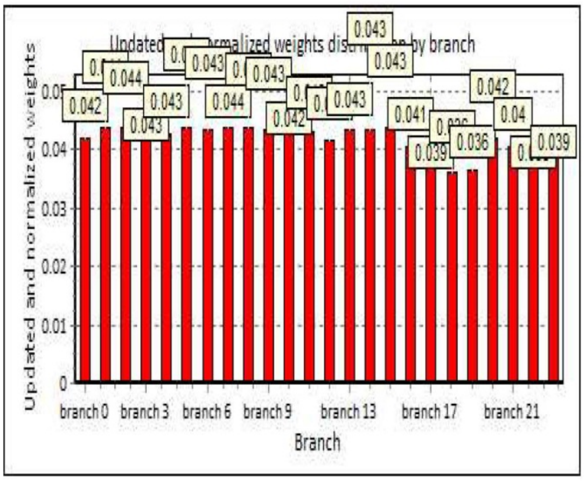
Main values

Mean exceedance rate a priori : **0.9047**
Updated rate : **0.9154**
Std deviation of exceedance rate a priori : **0.2635**
Updated std dev. : **0.2542**

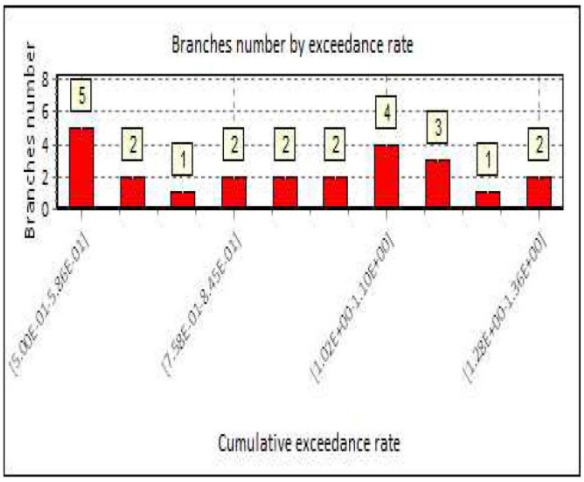
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

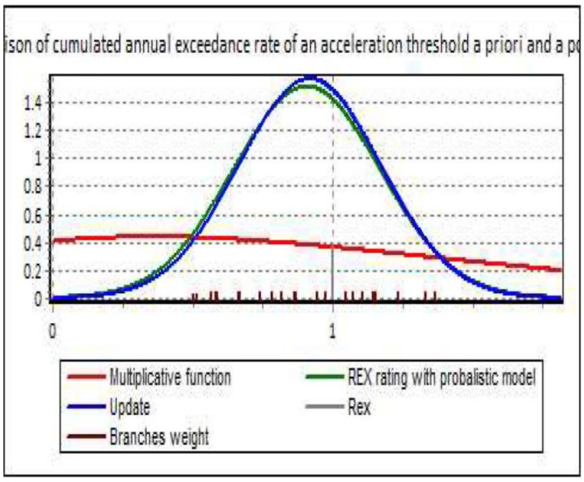


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Figure 18.Test 9. Updating of the seismic hazard considering REX historical, PGA level=50 cm/s2 and Magnitude - PGA relation. SAOF

6.4 UPDATING OF SEVERAL SITES USING DATA OF SEVERAL SITES

In the following tests, we selected 11 recording stations of the south-east corner of France to estimate a REX. The selected stations are situated at a minimum distance of 50 km to avoid correlation between stations. As we pointed out previously, the aim of this exercise is not to develop a detailed and precise REX and associated updating but much more to analyze the behavior of the Bayesian updating approach under different conditions and hypothesis in order to validate the methodology. The following tests are presented:

- Test 10: It was performed using the historical REX (using Mezcua et al. 2004 to define the punctual intensity and Atkinson and Kaka, 2007 to calculate PGA), an acceleration threshold of 10 cm/s^2
- Text 11: It was the same than test 10 but using an acceleration threshold of 50 cm/s^2 and using the French IPE to define the punctual intensity and the PS92 relation to convert intensity into PGA.
- Test 12: It was the same than test 11 but using an acceleration threshold of 100 cm/s^2
- Test 13: It was the same than test 11 but using an acceleration threshold of 200 cm/s^2
- Test 14: It was the same than test 10 but using the historical REX developed using the GMPE of Drouet et al. 2013.
- Test 15: It was the same than test 14 but supposing an acceleration threshold of 50 cm/s^2.
- Test 16: It was the same than test 14 but supposing an acceleration threshold of 100 cm/s^2
- Test 17: It was performed using the instrumental REX and an acceleration threshold of 5 cm/s^2
- Test 18: It was performed using the instrumental REX and an acceleration threshold of 5 cm/s^2

6.4.1 Test 10: REX historical, PGA level=10 cm/s^2 and Intensity-PGA relation

The following test was performed using as input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 10 cm/s^2.
- Minimum magnitude: 4.5.
- Sites considered for the analysis: ANTF, IRJO, OGAG, OGAN, OGAV, OGDH, OGDI, OGMO, OGTB; SAOF and STET (Figure 1 and Figure 2).
- Period of completeness of station: 82 years (events occurred from 1880 to 1962).
- REX: 35 (considering a historical period from 1880 to 1962). Taking into account the low acceleration threshold and the validity domain of Intensity-PGA relations, the acceleration values were obtained using the Mezcua et al. 2004 relation coupled with the Atkinson & Kaka, 2007 relation. Then, we obtained 35 exceedance during the period considered. Both relations were used in the article Mezcua et al. 2013, summarized in chapter 2.

The Figure 19 shows the comparison between the predicted exceedance rate by the *prior* mean seismic hazard curve (associated to PGA) during the estimated complete period of the set of 11 stations (using equivalent weight per branch) and the exceedance rate predicted by the *posterior* mean seismic hazard curve (using the weights calculated by the updating process) during the same period. The Figure 19 includes also the cumulated exceedance rate predicted by each one of the 24 models used in this test.

The historical REX is equal to 35 (biggest red dot in Figure 19). For information purposes, the Figure 19 shows also the REX obtained using the same hypothesis except the acceleration threshold, which were fixed to 50 and 100 cm/s^2. They will be used in the following tests. We note, again, that the REX is only an example or prototype used for academic purpose only. If other attenuation relationships in terms of intensity are used and they are coupled with other intensity-PGA relations, the REX could be significantly different. In other working package of SIGMA project, there are some teams working on the development of new intensity attenuation relations to improve the reliability of the historical REX. When these relations will be mature enough, the development of a more detailed REX, taking into account soil conditions of sites, for example, will be possible.

In this case, effects of the updating method show a special behavior. The *posterior* curve is closer to the REX and more penalizing than the *prior* curve, around 10 cm/s^2. Nevertheless, for high accelerations (or return periods), the *prior* seismic hazard curve is more penalizing. This is other typical example showing that the update of the seismic hazard should be performed, preferably, using thresholds of acceleration close to the acceleration levels of the return period that we would like to update. The use of a single acceleration level to update the entire seismic hazard curve could lead to a bias in part of the hazard curve.

The Table 8 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard, at 11 seismic stations.

The results show that the update of the seismic hazard increases the cumulated mean exceedances of 10 cm/s^2 at 11 stations (28.3 *a priori* and 33.7 *a posteriori,* Figure 19 *and* Figure 20). The standard deviation *a posteriori* of the distribution of exceedances is smaller (4.57 *a posteriori* against 8.22 *a priori,* Figure 20). This is a general tendency. The updating process tends to reduce the uncertainty.

The results of Table 8 show also that the effects of the updating process are not the same for all sites where the seismic hazard was updated. For example, in ANTF station at 10000 years-return period the seismic hazard is increased. Nevertheless, the seismic hazard in OGAG station at the same return period is reduced slightly. Again, this is produced by the different slopes of the seismic hazard curves at the different stations.

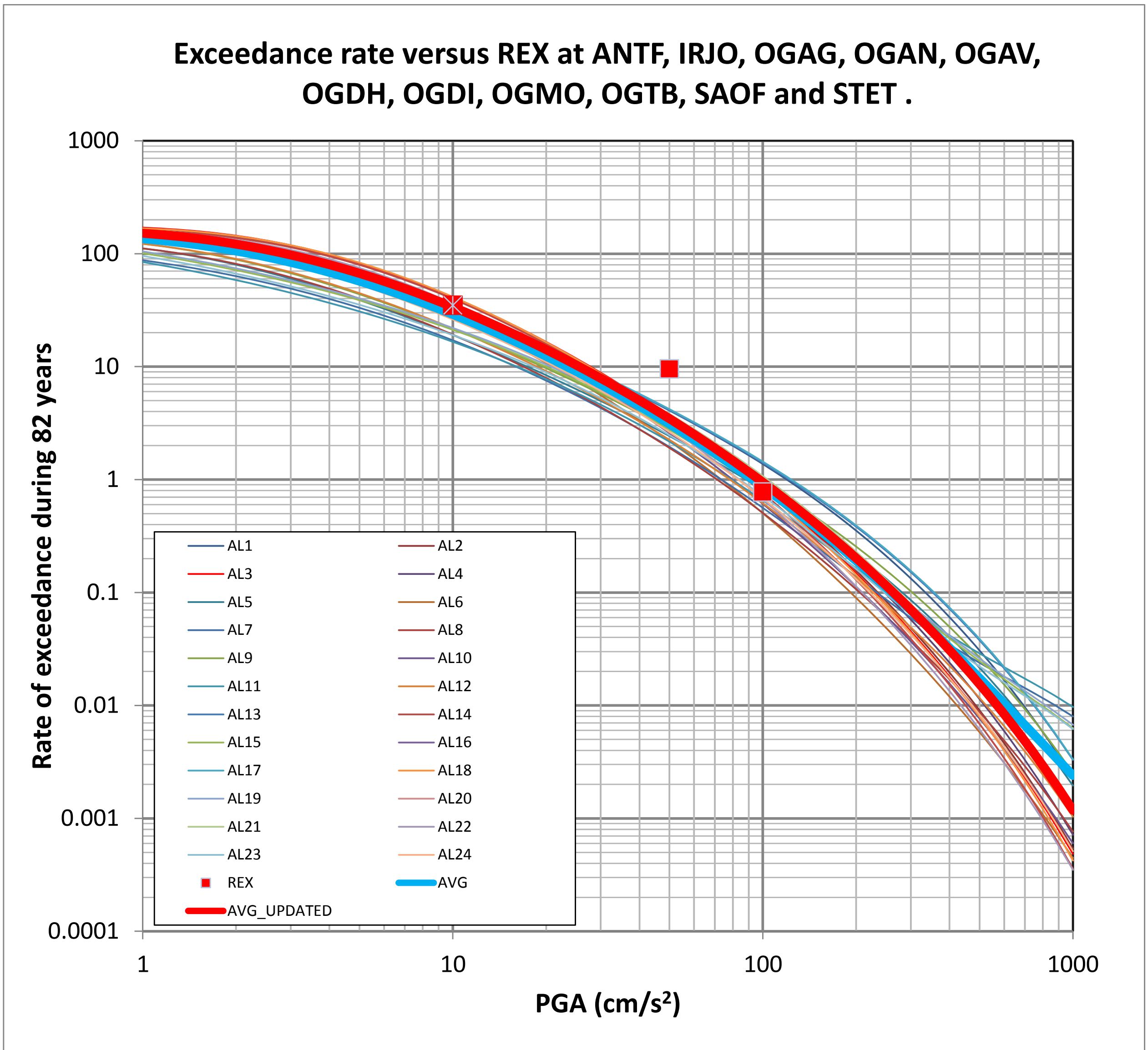


Figure 19. Test 10. Comparison of exceedance rate during the working period of the station and the historical REX. Set of 11 stations.

PGA (cm/s²)	Prior					Posterior				
	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
ANTF	18	46	68	150	202	19	49	71	154	207
IRJO	24	67	98	203	265	28	76	110	223	289
OGAG	26	67	97	204	271	29	70	99	203	264
OGAN	25	68	102	225	305	27	73	107	228	302
OGAV	23	60	86	177	230	27	67	95	189	244
OGDH	23	63	95	211	283	24	66	98	214	285
OGDI	24	62	91	195	261	27	66	94	195	257
OGMO	26	65	94	196	258	29	68	96	194	252
OGTB	27	71	105	226	303	30	75	109	226	297
SAOF	28	75	110	227	296	31	81	116	236	305
STET	27	71	103	217	287	30	75	108	220	287

Table 8. Mean PGA at different return periods, before and after the update of seismic hazard. Test 10.

UPDATE METHOD

TEST NAME : Test 10

GEOTER | EDF

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **10.0**

REX (Exceedance number) : **35.000000**

Test properties

REX_HISTO
M>=4.5
PGA>=10
Date>1880
Per.fonc: 82
Mezcua04 + Atkk07

Source directory : C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs

Sites - (11)

ANTF	OGDH
IRJO	OGDI
OGAG	OGMO
OGAN	OGTB
OGAV	SAOF
	STET

Main values

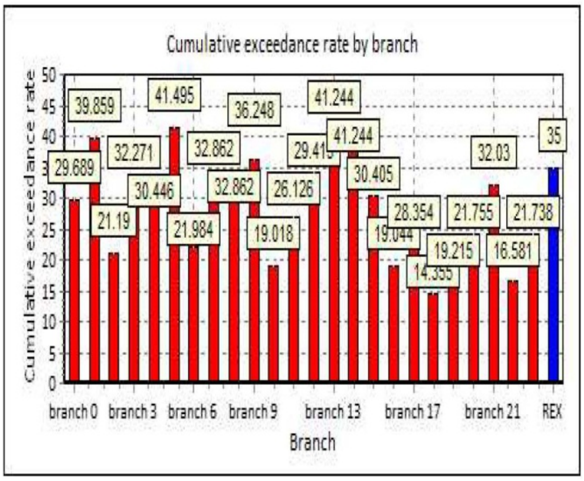
Mean exceedance rate a priori : **28.3094**

Updated rate : **33.7181**

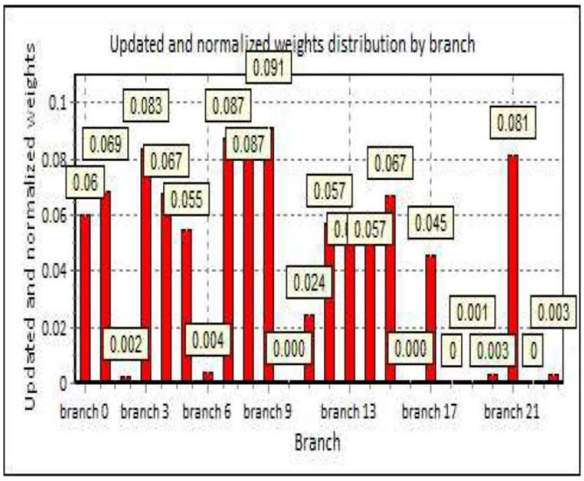
Std deviation of exceedance rate a priori : **8.2270**

Updated std dev. : **4.5785**

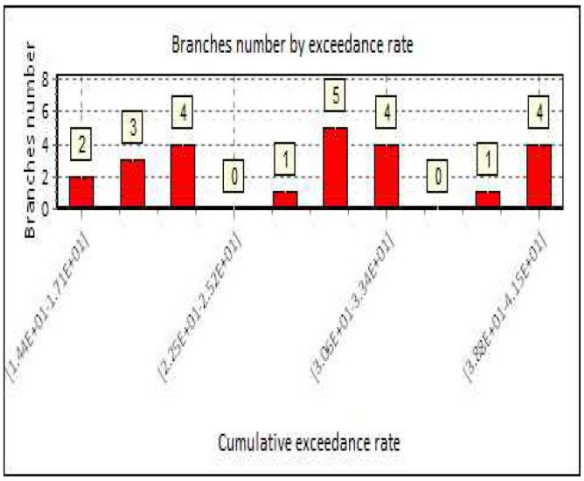
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

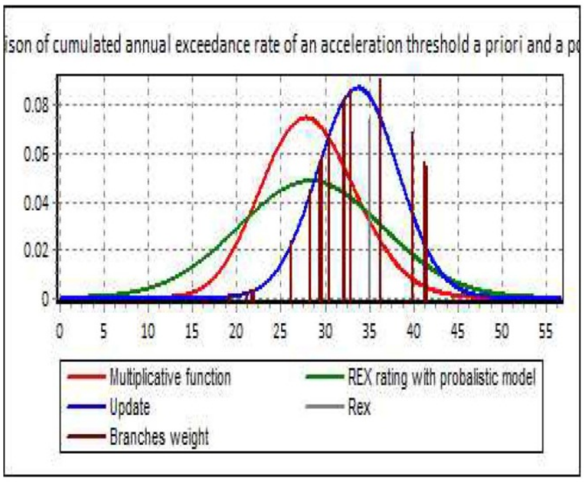


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Figure 20. Test 10. Updating of the seismic hazard considering REX historical, PGA level=10 cm/s2 and Intensity-PGA relation

6.4.2 Test 11: REX historical, PGA level=50 cm/s^2 and Intensity-PGA relation

The following test was performed using as input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 50 cm/s^2.
- Minimum magnitude: 4.5.
- Sites considered for analysis: ANTF, IRJO, OGAG, OGAN, OGAV, OGDH, OGDI, OGMO, OGTB; SAOF and STET.
- Period of completeness of station: 112 years (events occurred from 1850 to 1962).
- REX: 13 (historical period, from 1850 to 1962). The acceleration values were obtained using the French intensity prediction equation developed for the Provence region (stations OGAV, IRJO, OGDI) and the French intensity prediction equation developed for alpine region (rest of stations) coupled with the PS92 relation to convert intensities into PGA. Then, we obtained 13 exceedance during the period considered.

The Figure 21 shows the comparison between the cumulated exceedance rate predicted by the *prior* mean seismic hazard curve (associated to PGA) during the estimated complete period of the set of 11 stations (using equivalent weight per branch) and the cumulated exceedance rate predicted by the *posterior* mean seismic hazard curve (using the weights calculated by the updating process) during the same period. The Figure 21 includes also the cumulated exceedance rate predicted by each one of the 24 models used in this test.

The historical REX is equal to 13 (biggest red dot in Figure 21). For information purposes, the Figure 21 shows also the REX obtained using the same hypothesis except the acceleration threshold, which was fixed to 10 and 100 cm/s^2. They are used in test 10 and 12.

The application of the updating method leads to a moderate increase of the mean seismic hazard. The *posterior* curve is nearer to the REX and more penalizing than the *prior* curve for all accelerations.

The Table 9 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard, at 11 stations selected.

The results show that the update of the seismic hazard increases the global predicted exceedances of 50 cm/s^2 at 11 stations (global *prior* exceedance rate of 4.16 and *posterior* of 5.27*,* Figure 21 and Figure 22). The increase of the seismic hazard in the different sites is different: 10% for ANTF and 25% for IRJO at 475 years of return period. At 10000 years of return period the effects are also different (i.e. 20% of increase in ARFT and 25% in IRJO).

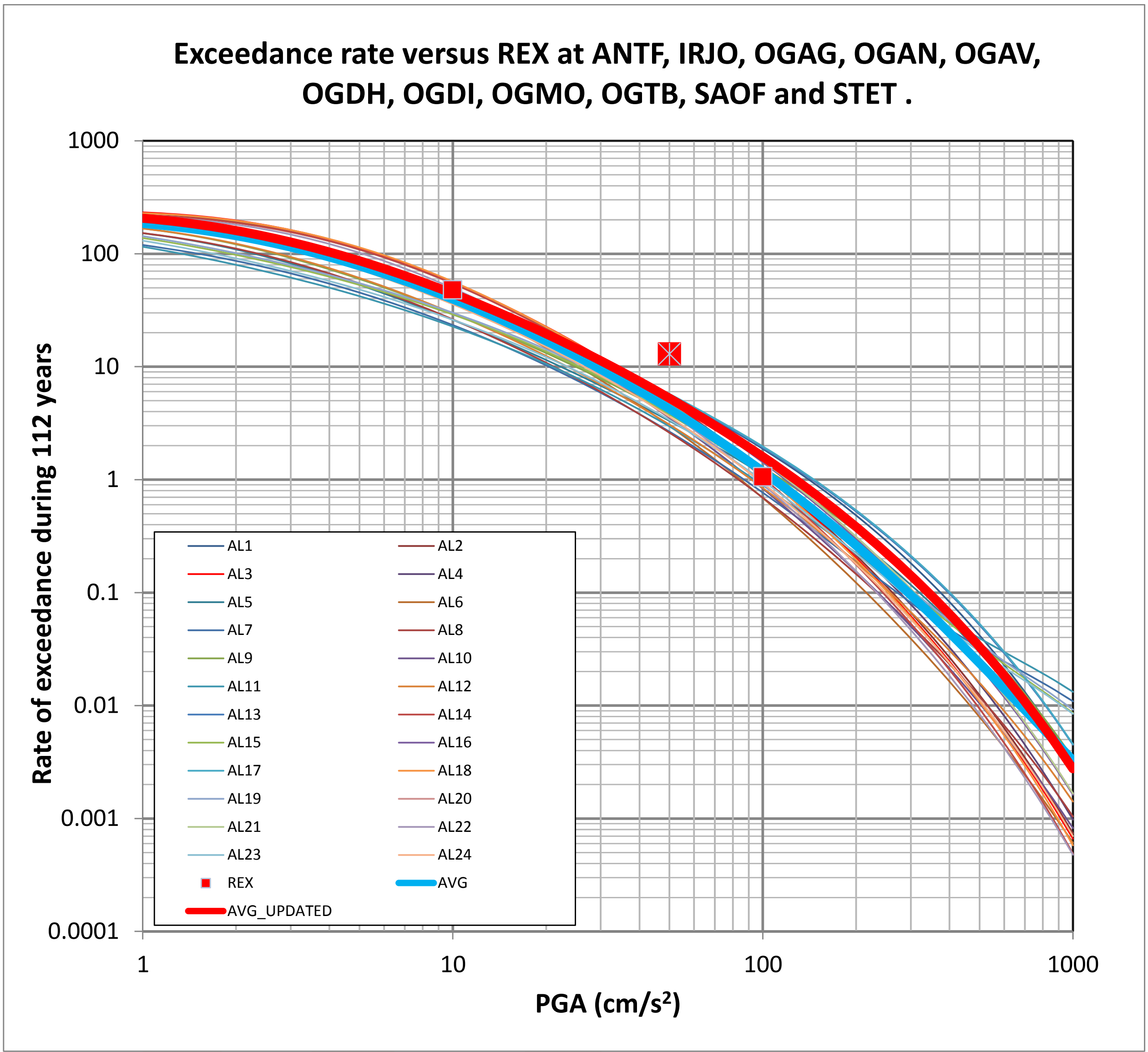

Figure 21. Test 11. Comparison of exceedance rate during the working period of the station and the historical REX. Set of 11 stations.

PGA (cm/s²)	Prior					Posterior				
	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
ANTF	18	46	68	150	202	19	51	76	176	239
IRJO	24	67	98	203	265	30	85	124	252	325
OGAG	26	67	97	204	271	29	76	111	236	309
OGAN	25	68	102	225	305	28	81	122	268	355
OGAV	23	60	86	177	230	28	71	103	207	267
OGDH	23	63	95	211	283	24	72	112	251	334
OGDI	24	62	91	195	261	27	71	104	225	299
OGMO	26	65	94	196	258	29	73	106	220	288
OGTB	27	71	105	226	303	30	83	124	265	349
SAOF	28	75	110	227	296	33	90	131	271	351
STET	27	71	103	217	287	31	82	120	253	332

Table 9. Mean PGA at different return periods, before the update of seismic hazard. Test 11.

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UPDATE METHOD

TEST NAME : Test 11

GEOTER EDF

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **50.0**

REX (Exceedance number) : **13.000000**

Test properties

REX_HISTO
M>=4.5
PGA>=50
Date>1850
Per.fonc: 112
IAlps_Pro + PS92

Source directory : *C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs*

Sites - (11)

ANTF
IRJO
OGAG
OGAN
OGAV
OGDH
OGDI
OGMO
OGTB
SAOF
STET

Main values

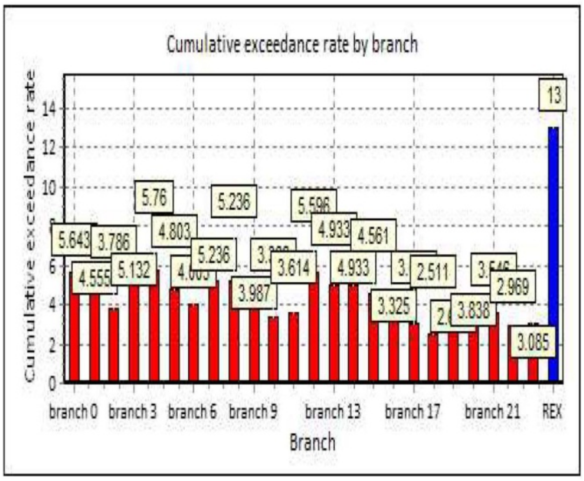
Mean exceedance rate a priori : **4.1692**

Std deviation of exceedance rate a priori : **1.0061**

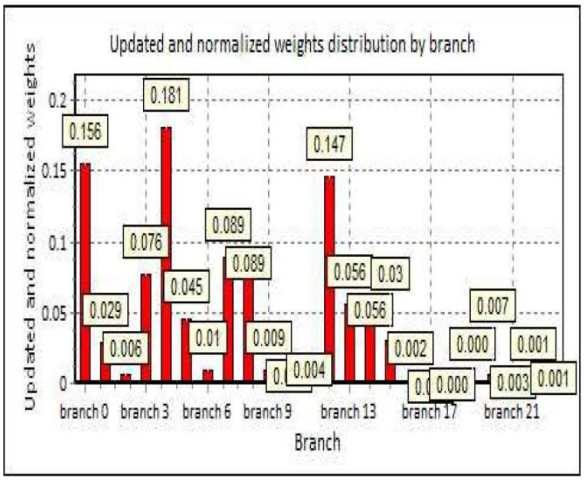
Updated rate : **5.2792**

Updated std dev. : **0.4544**

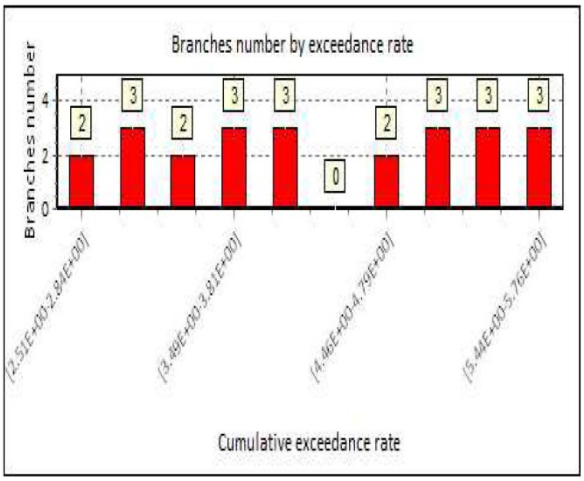
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

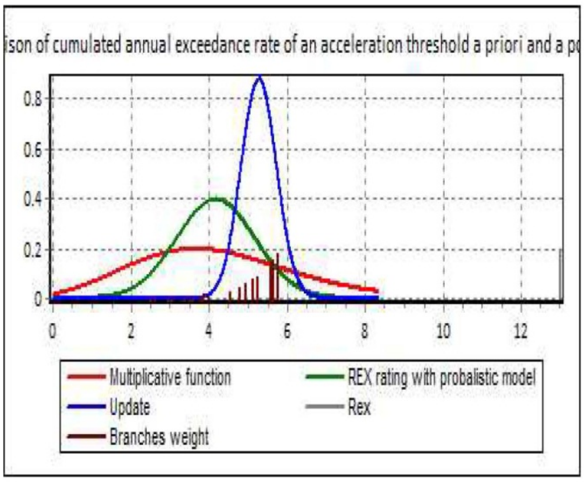


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Figure 22. Test 11. Updating of the seismic hazard considering REX historical, PGA level=50 cm/s2 and Intensity-PGA relation

6.4.3 Test 12: REX historical, PGA level=100 cm/s^2 and Intensity-PGA relation

The following test is equivalent to the test 9 but using the Drouet 2013 conversion instead of the intensity-PGA conversion. It was performed using as input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 100 cm/s^2.
- Minimum magnitude: 4.5.
- Sites considered for analysis: ANTF, IRJO, OGAG, OGAN, OGAV, OGDH, OGDI, OGMO, OGTB, SAOF and STET.
- Period of completeness of station: 112 years (events occurred from 1850 to 1962).
- REX: 2 (considering a historical period of stations, from 1850 to 1962). The acceleration values were obtained using the French intensity prediction equation developed for the Provence region (stations OGAV, IRJO, OGDI) and the French intensity prediction equation developed for alpine region (rest of stations) coupled with the PS92 relation to convert intensities into PGA . The difference is very important.

The Figure 23 shows the comparison between the cumulated exceedance rate predicted by the *prior* mean seismic hazard curve (associated to PGA) during the estimated complete period of the set of 11 stations (using equivalent weight per branch) and the cumulated exceedance rate predicted by the *posterior* mean seismic hazard curve (using the weights calculated by the updating process) during the same period. The Figure 23 includes also the cumulated exceedance rate predicted by each one of the 24 models used in this test.

The historical REX is equal to 2 (biggest red dot in Figure 23). For information purposes, the Figure 23 shows also the REX obtained using the same hypothesis except the acceleration threshold, which were fixed to 10 and 50 cm/s^2. They were used in test 10 and test 11.

The application of the updating method leads to a very small reduction of the seismic hazard. The *posterior* curve is a very good agreement with the REX. In this case, the predictive models are able to reproduce perfectly the REX. The effect of the updating process is to re-fit the mean seismic hazard curves.

The Table 10 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard.

The results show that the update of the seismic hazard decreases the mean exceedances of 100 cm/s^2 (*prior* global exceedance rate of 2.20 and *posterior* of 2.14, Figure 24). The decrease of the seismic hazard in the different sites is small at all return periods.

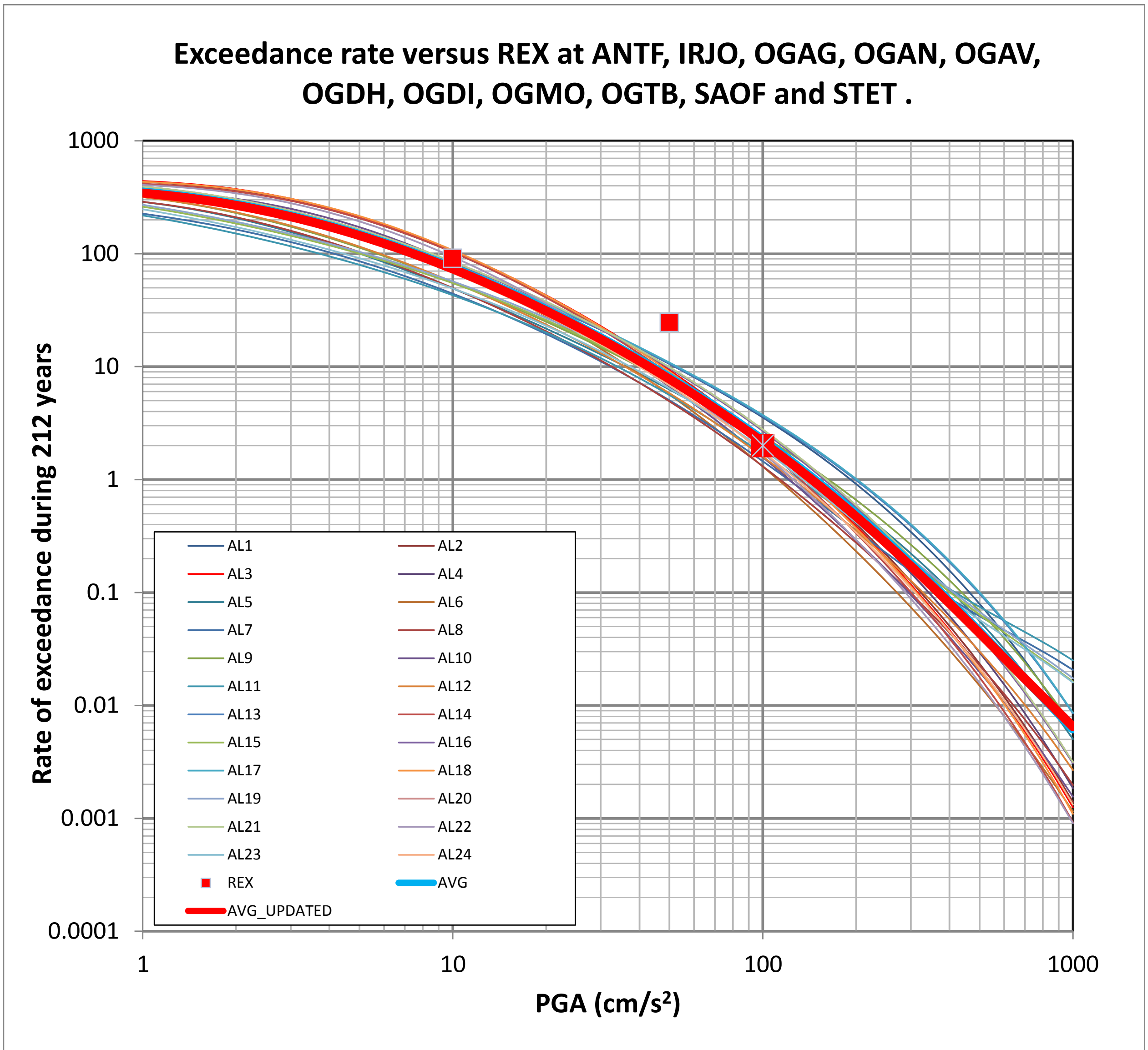


Figure 23. Test 12. Comparison of exceedance rate during the working period of the station and the historical REX. Set of 11 stations.

PGA (cm/s^2)	Prior					Posterior				
	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
ANTF	18	46	68	150	202	18	46	68	148	199
IRJO	24	67	98	203	265	24	66	96	199	260
OGAG	26	67	97	204	271	26	66	96	201	267
OGAN	25	68	102	225	305	25	68	100	220	298
OGAV	23	60	86	177	230	23	60	86	175	228
OGDH	23	63	95	211	283	23	63	94	207	277
OGDI	24	62	91	195	261	24	62	90	192	256
OGMO	26	65	94	196	258	26	65	93	193	254
OGTB	27	71	105	226	303	27	71	103	222	298
SAOF	28	75	110	227	296	28	74	108	222	290
STET	27	71	103	217	287	27	70	102	213	281

Table 10. Mean PGA at different return periods, before the update of seismic hazard. Test 12.

UPDATE METHOD

TEST NAME : Test 12

GEOTER edf

Test specifications

Files number :	**24**
K value :	**1.01**
Acceleration threshold (cm/s²) :	**100.0**
REX (Exceedance number) :	**2.000000**

Test properties

REX_HISTO
M>=4.5
PGA>=100
Date>1750
Per.fonc: 212
IAlps_Pro + PS92

Source directory : C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs\

Sites - (11)

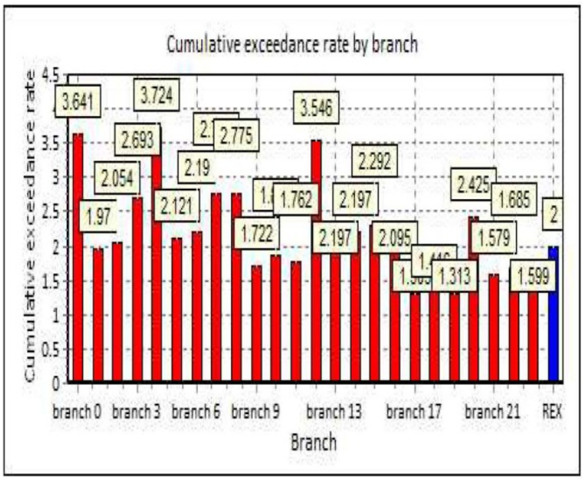
ANTF	OGDH
IRJO	OGDI
OGAG	OGMO
OGAN	OGTB
OGAV	SAOF
	STET

Main values

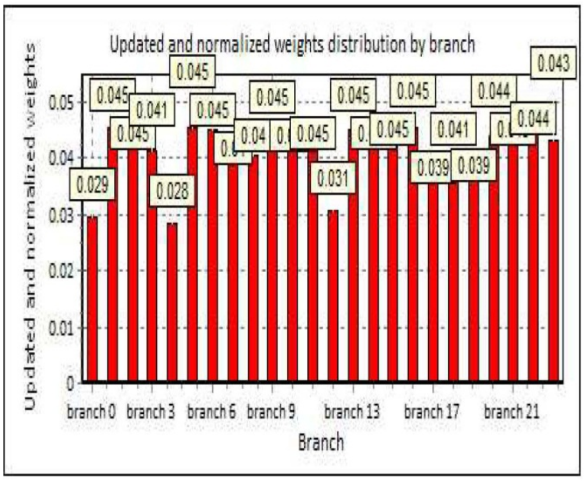
Mean exceedance rate a priori : **2.2051** *Updated rate :* **2.1476**

Std deviation of exceedance rate a priori : **0.6925** *Updated std dev. :* **0.6152**

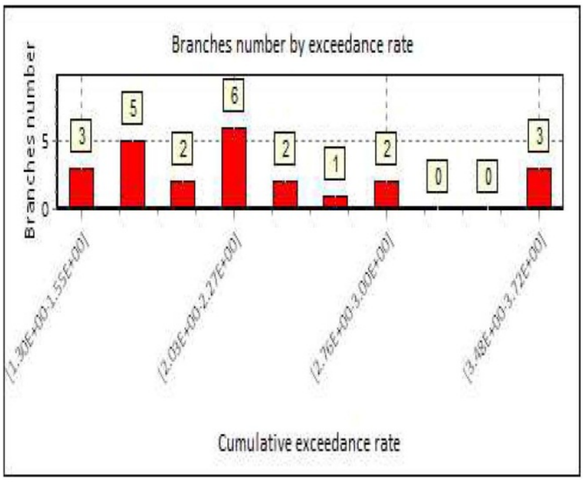
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

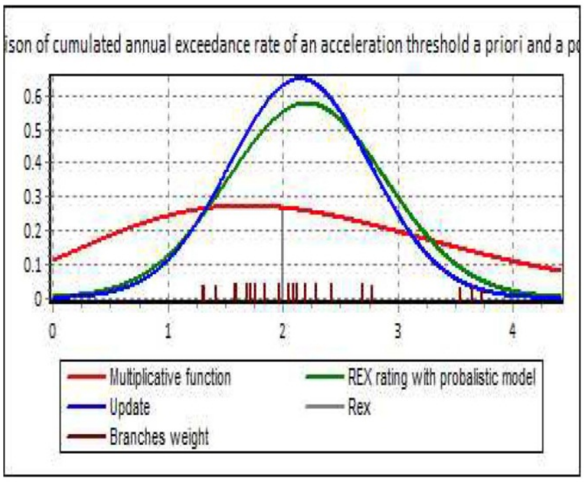


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Figure 24. Test 12. Updating of the seismic hazard considering REX historical, PGA level=10 cm/s2 and magnitude-PGA relation

6.4.4 Test 13: REX historical, PGA level=200 cm/s2, PGA and Magnitude-PGA relation

The following test was performed using as input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 200 cm/s^2.
- Minimum magnitude: 4.5.
- Sites considered for analysis: ANTF, IRJO, OGAG, OGAN, OGAV, OGDH, OGDI, OGMO, OGTB, SAOF and STET.
- Period of completeness of station: 462 years per station.
- REX: 0 (considering a historical period of stations, from 1500 to 1962). The acceleration values were obtained using the French IPE developed for the Provence region (stations OGAV, IRJO, OGDI) and the French IPE developed for alpine region (rest of stations) coupled with the PS92 relation to convert intensities into PGA. Using the Drouet 2013 or Cauzzi & Faccioli, 2008 GMPEs, the REX is unchanged: 0 exceedances of 200 cm/s^2. Then, we obtained 0 exceedance of the acceleration level selected during the period of observation considered.

In this case, the historical REX using an acceleration threshold of 200 cm/s^2 is equal to 0. The red dots presented in Figure 25 correspond to the REX using the same hypothesis but with different acceleration levels: 10, 50 and 100 cm/s^2, (used in tests 10, 11 and 12).

The application of the updating method show a reduction of the exceedance rate around 200 cm/s^2 and almost equivalent exceedance *prior* and *posterior* rates for low return periods.

The Table 11 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard.

The analysis of Table 11 shows that the update of the seismic hazard decreases the mean exceedance around 200 cm/s^2 (global *prior* exceedance rate of 1.07 and *posterior* of 0.96, Figure 25 and Figure 26). The decrease of the seismic hazard in the different sites, at 10000 years of return period is around 5%-10%. In the case of SAOF, for example, the PGA associated to 10000 years of return period decreases from 296 cm/s^2 *a priori* to 276 cm/s^2 *a posteriori*.

Among all tests performed, maybe is this test 13 is the most similar to a real application. It has been performed using a high acceleration threshold (200 cm/s^2) and it used a long recording period (462 years x 11 stations). Therefore, for this threshold of acceleration, the independence of stations is almost guaranteed because they have been selected with a minimum distance between them (50 km) and the probability that an earthquake with M<6.5 produces 0.2 g or higher at 2 stations simultaneously is very low.

The period of completeness of these accelerations levels (200 cm/s^2) and magnitude ranges (M around 6.0) can be well defined ant it is the longest of the catalogue.

Finally, it should be noted that all the stations used are located in the same region, in the same seismotectonic context.

The tests 10 to 13 show different examples of application of the updating methodology using different REX obtained with different PGA thresholds. .

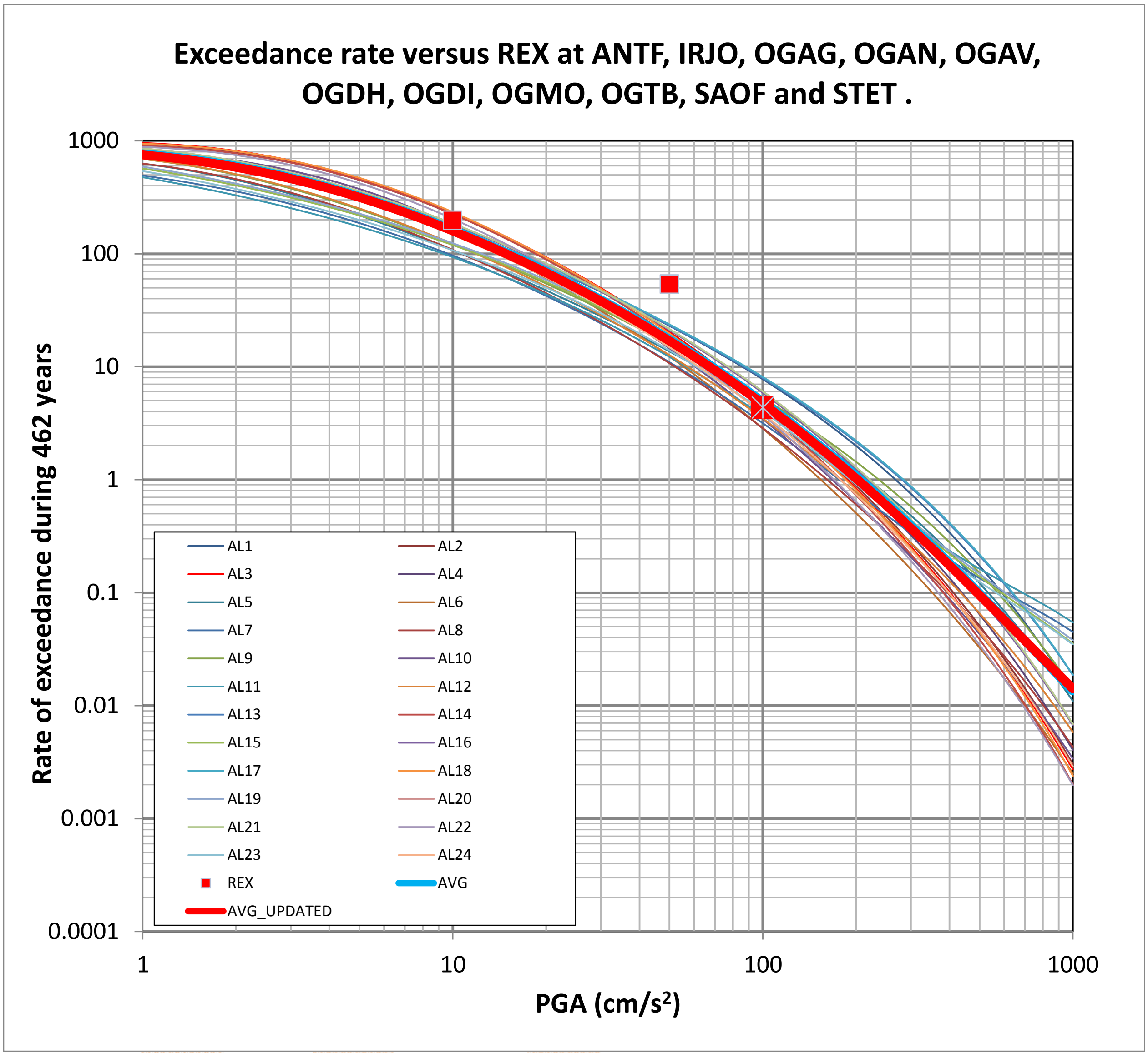


Figure 25. Test 13. Comparison of exceedance rate during the complete period of the stations and the historical REX. Set of 11 stations.

PGA (cm/s^2)	Prior					Posterior				
	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
ANTF	18	46	68	150	202	18	45	66	141	189
IRJO	24	67	98	203	265	23	63	91	188	245
OGAG	26	67	97	204	271	26	65	93	191	253
OGAN	25	68	102	225	305	25	65	96	208	281
OGAV	23	60	86	177	230	22	58	83	168	219
OGDH	23	63	95	211	283	23	61	90	196	262
OGDI	24	62	91	195	261	24	60	87	183	243
OGMO	26	65	94	196	258	26	63	90	185	243
OGTB	27	71	105	226	303	27	68	99	210	281
SAOF	28	75	110	227	296	27	72	104	212	276
STET	27	71	103	217	287	27	68	99	204	268

Table 11. Mean PGA at different return periods, after the update of seismic hazard. Test 13.

UPDATE METHOD

TEST NAME : Test 13

GEOTER edf

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **200.0**

REX (Exceedance number) : **0.000000**

Test properties

REX histo
M>=4.5
PGA>=200 cm/s2
Data>1500
Obs. Per.: 462
Droet2013

Source directory : C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs

Sites - (11)

ANTF	OGDH
IRJO	OGDI
OGAG	OGMO
OGAN	OGTB
OGAV	SAOF
	STET

Main values

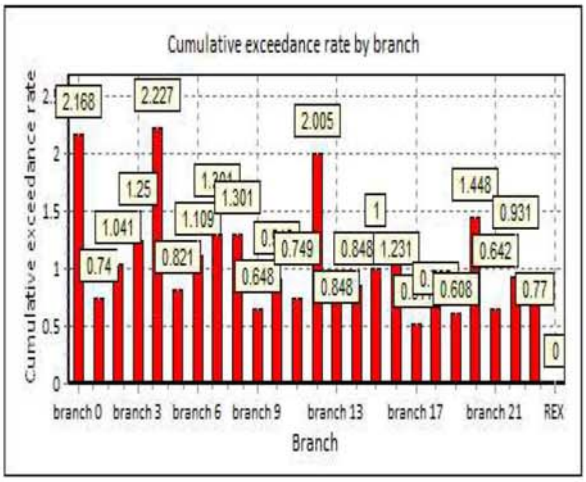
Mean exceedance rate a priori : **1.0791**

Updated rate : **0.9180**

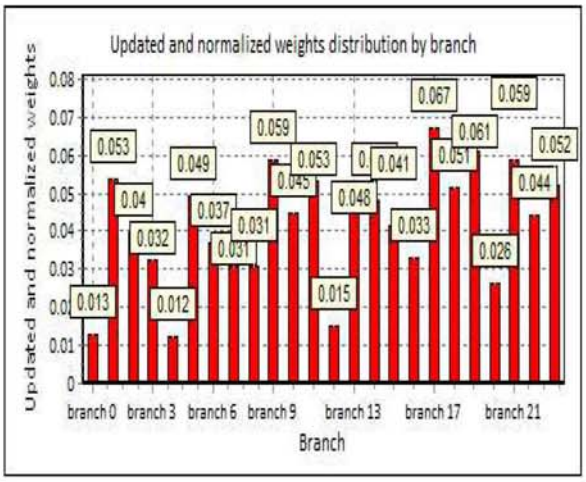
Std deviation of exceedance rate a priori : **0.4758**

Updated std dev. : **0.3366**

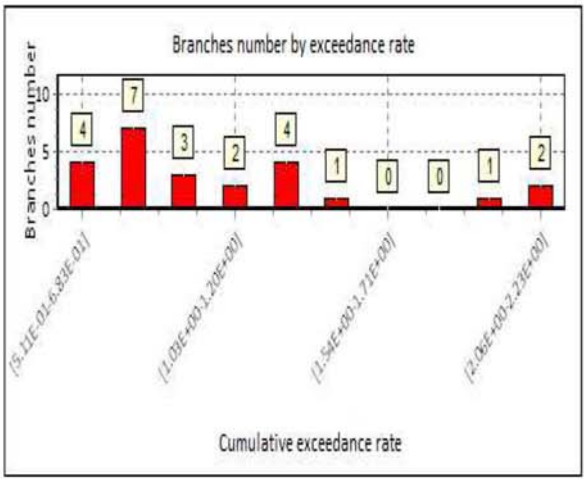
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

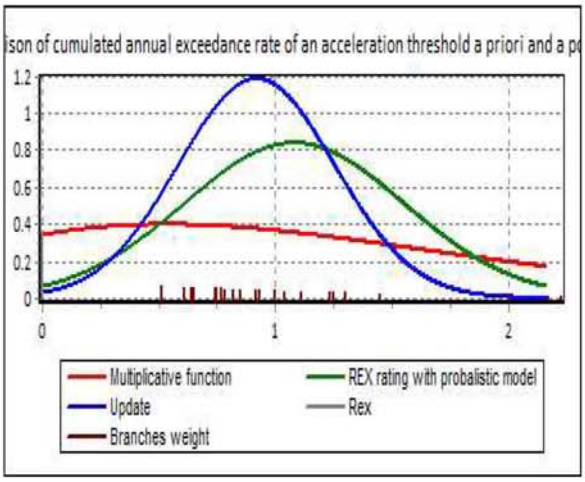


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Figure 26. Test 13. Updating of the seismic hazard considering REX historical, PGA level=200 cm/s2 and magnitude-PGA relation

6.4.5 Test 14: REX historical, PGA level=10 cm/s² and Magnitude-PGA relation

This test is equivalent to the test 10 but using the Drouet 2013 conversion instead of the intensity-PGA conversion. It was performed using as input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 10 cm/s^2.
- Minimum magnitude: 4.5.
- REX: 19 (considering a historical period of stations, from 1880 to 1962). The acceleration values were obtained using Drouet 2013 GMPE. We obtained 19 exceedances. Using the Intensity to PGA conversions (test 10) we got 35 observations. The difference in REX estimation is, therefore, significant.
- Sites considered for analysis: ANTF, IRJO, OGAG, OGAN, OGAV, OGDH, OGDI, OGMO, OGTB, SAOF and STET.
- Period of completeness of station: 82 years (events from 1850 to 1962).

The Figure 27 shows the comparison between the cumulated exceedance rate predicted by the prior mean seismic hazard curve (associated to PGA) during the estimated complete period of the set of 11 stations (using equivalent weight per branch) and the cumulated exceedance rate predicted by the posterior mean seismic hazard curve (using the weights calculated by the updating process) during the same period. The Figure 27 includes also the cumulated exceedance rate predicted by each one of the 24 models used in this test.

The historical REX is equal to 19 (biggest red dot in Figure 27). For information purposes, the Figure 27 shows also the REX obtained using the same hypothesis except the acceleration threshold, which were fixed to 50 and 100 cm/s^2. They will be used in test 15 and test 16.

In this case, effects of the updating method consist in a reduction of the seismic hazard. The *posterior* curve is a good agreement with the REX. In this case, the predictive models are perfectly consistent with the REX. The effect of the updating process is to re-fit the mean seismic hazard curves.

The Table 12 shows the comparison of mean PGA obtained at different return periods, before and after the update of the seismic hazard.

The results show a decrease of the mean exceedances of 10 cm/s^2 (global prior exceedance rate of 28.30 and *posterior* of 20.77, Figure 28). The decrease of the seismic hazard at the different sites is evident at 100 years of return period (with accelerations near to 10 cm/s^2). At 10000 years of return period, the effects of the updating process are different: in ANTF the seismic hazard is equivalent; in IRJO we observe a decrease of almost 20% and in OGAG we observe an increase of 5%. Again the global results of the updating process using an acceleration level cannot be extrapolated at all acceleration levels. Indeed, the global behavior observed using the set of 11 stations can be different at each of the stations used.

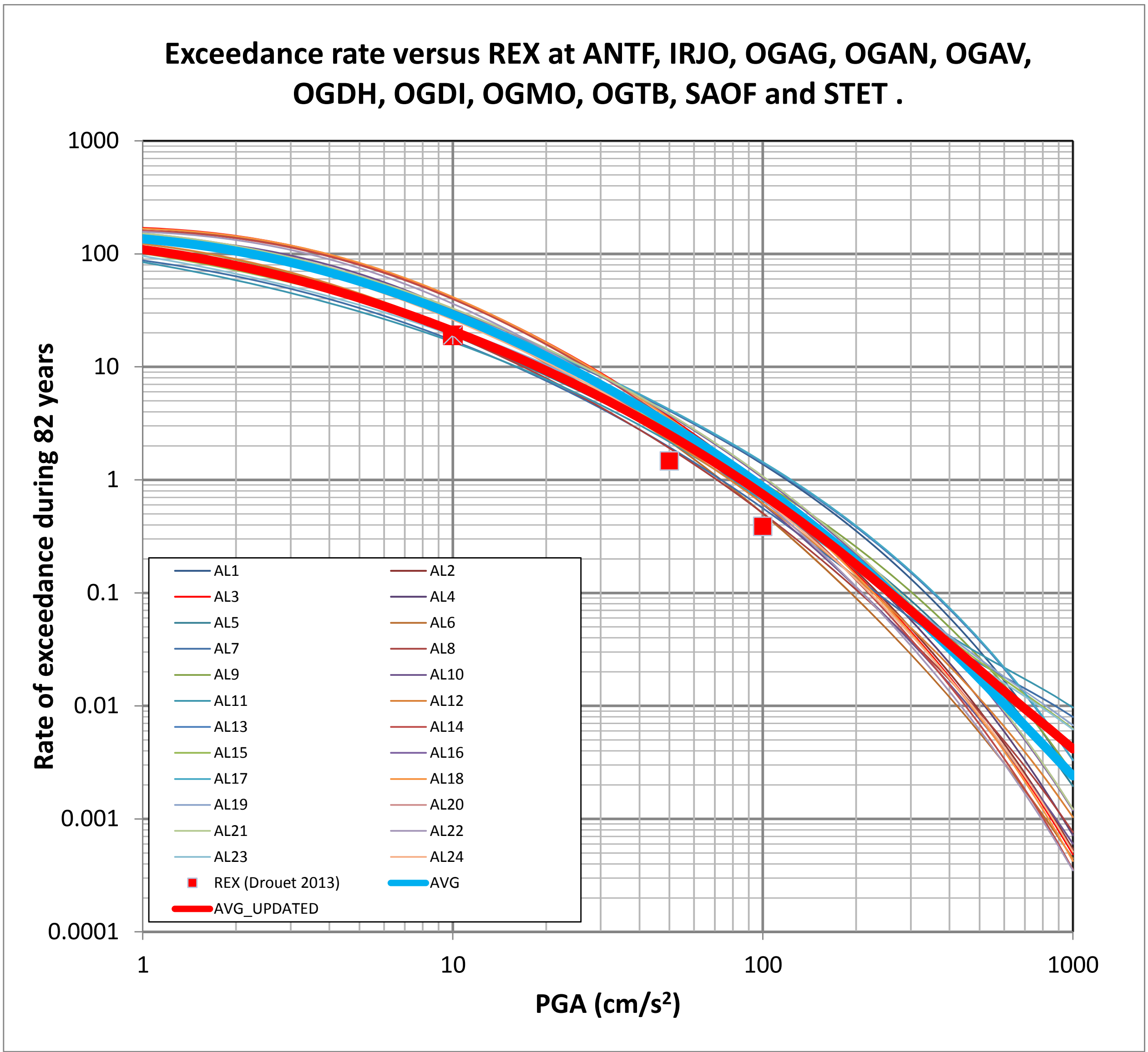
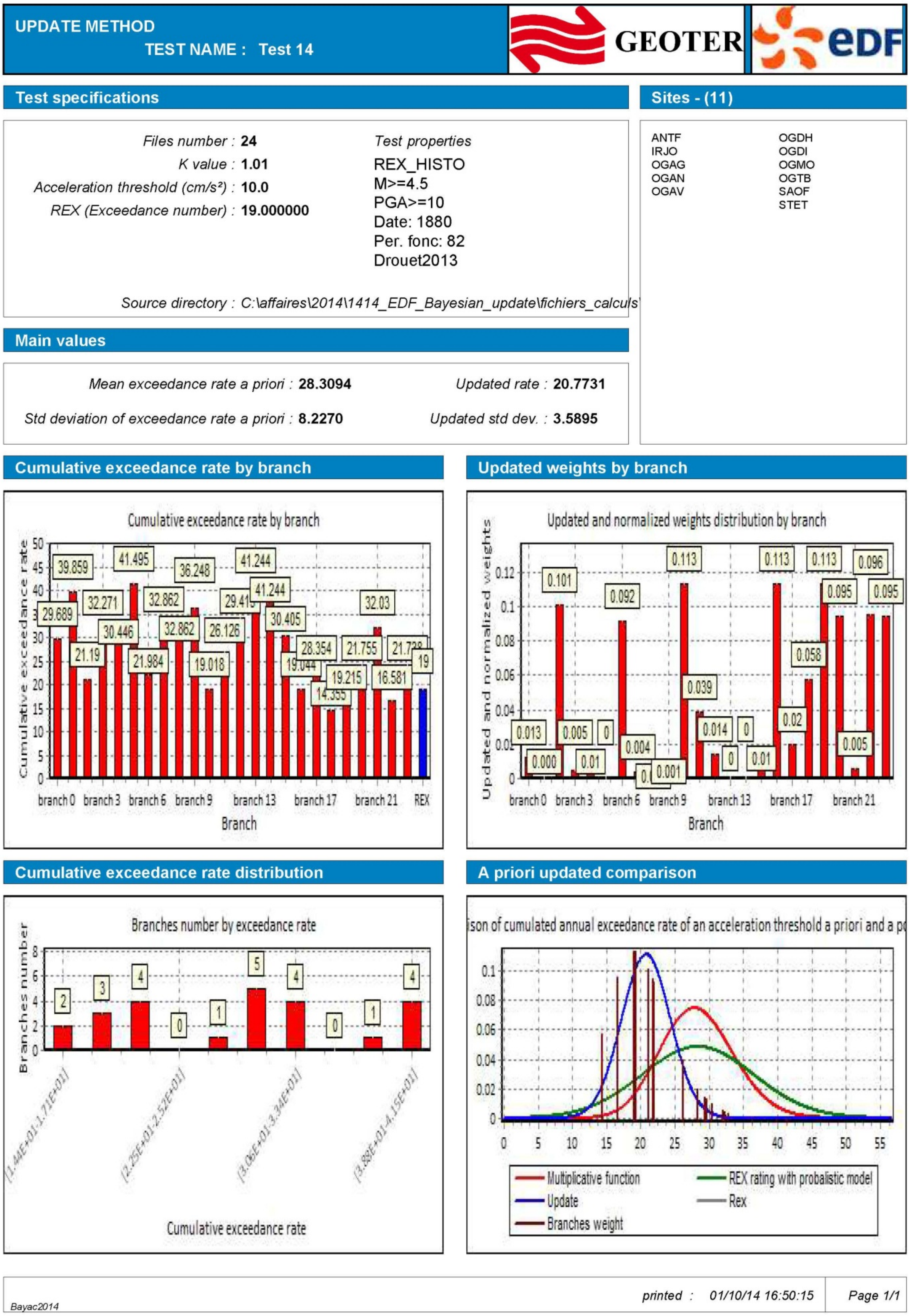


Figure 27. Test 14. Comparison of exceedance rate during the working period of the station and the historical REX. Set of 11 stations.

PGA (cm/s^2)	Prior					Posterior				
	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
ANTF	18	46	68	150	202	15	43	65	149	202
IRJO	24	67	98	203	265	17	52	79	171	226
OGAG	26	67	97	204	271	23	63	94	209	286
OGAN	25	68	102	225	305	22	63	96	222	311
OGAV	23	60	86	177	230	16	47	71	155	206
OGDH	23	63	95	211	283	20	61	93	210	284
OGDI	24	62	91	195	261	20	58	87	197	269
OGMO	26	65	94	196	258	22	61	91	200	268
OGTB	27	71	105	226	303	23	66	100	229	318
SAOF	28	75	110	227	296	23	67	100	215	284
STET	27	71	103	217	287	23	65	97	213	287

Table 12. Mean PGA at different return periods, after the update of seismic hazard. Test 14.



UPDATE METHOD

TEST NAME : Test 14

GEOTER | EDF

Test specifications

Files number :	**24**
K value :	**1.01**
Acceleration threshold (cm/s²) :	**10.0**
REX (Exceedance number) :	**19.000000**

Test properties

REX_HISTO
M>=4.5
PGA>=10
Date: 1880
Per. fonc: 82
Drouet2013

Source directory : C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs\

Sites - (11)

ANTF, IRJO, OGAG, OGAN, OGAV, OGDH, OGDI, OGMO, OGTB, SAOF, STET

Main values

Mean exceedance rate a priori :	**28.3094**	*Updated rate :*	**20.7731**
Std deviation of exceedance rate a priori :	**8.2270**	*Updated std dev. :*	**3.5895**

Cumulative exceedance rate by branch

Updated weights by branch

Cumulative exceedance rate distribution

A priori updated comparison

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Figure 28. Test 14. Updating of the seismic hazard considering REX historical, PGA level=10 cm/s2 and magnitude-PGA relation

6.4.6 Test 15: REX historical, PGA level=50 cm/s^2 and Magnitude-PGA relation

The following test is equivalent to the test 11 but using the Drouet 2013 conversion instead of the intensity-PGA conversion. It was performed using as input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 50 cm/s^2.
- Minimum magnitude: 4.5.
- Sites considered for analysis: ANTF, IRJO, OGAG, OGAN, OGAV, OGDH, OGDI, OGMO, OGTB; SAOF and STET.
- Period of completeness of station: 112 years (events from 1850 to 1962).
- REX: 2 (considering a historical period of stations, from 1850 to 1962). The acceleration values were obtained using Drouet 2013 ground motion prediction equation. Then, we obtained 2 exceedances of the acceleration level selected during the period of observation considered.

The Figure 29 shows the comparison between the cumulated exceedance rate predicted by the *prior* mean seismic hazard curve (associated to PGA) during the estimated complete period of the set of 11 stations (using equivalent weight per branch) and the cumulated exceedance rate predicted by the *posterior* mean seismic hazard curve (using the weights calculated by the updating process) during the same period. The Figure 29 includes also the cumulated exceedance rate predicted by each one of the 24 models used in this test.

The historical REX is equal to 2 (biggest red dot in Figure 29). For information purposes, the Figure 29 shows also the REX obtained using the same hypothesis except the acceleration threshold, which were fixed to 10 and 100 cm/s^2. They were used in tests 14 and 16.

In this case, the application of the updating method leads to a reduction of the seismic hazard. The *posterior* curve is closer to the REX.

The Table 13 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard, in the 11 selected sites.

The analysis of Table 13 shows that the update of the seismic hazard decreases the mean exceedances of 50 cm/s^2 (global *prior* exceedance rate of 4.17 and *posterior* of 3.72*,* Figure 30). The decrease of the seismic hazard in the different sites is weak at 475 years of return period (with accelerations near to 50 cm/s^2). At 10000 years of return period, the effects of the updating process are similar in all sites, showing small reductions.

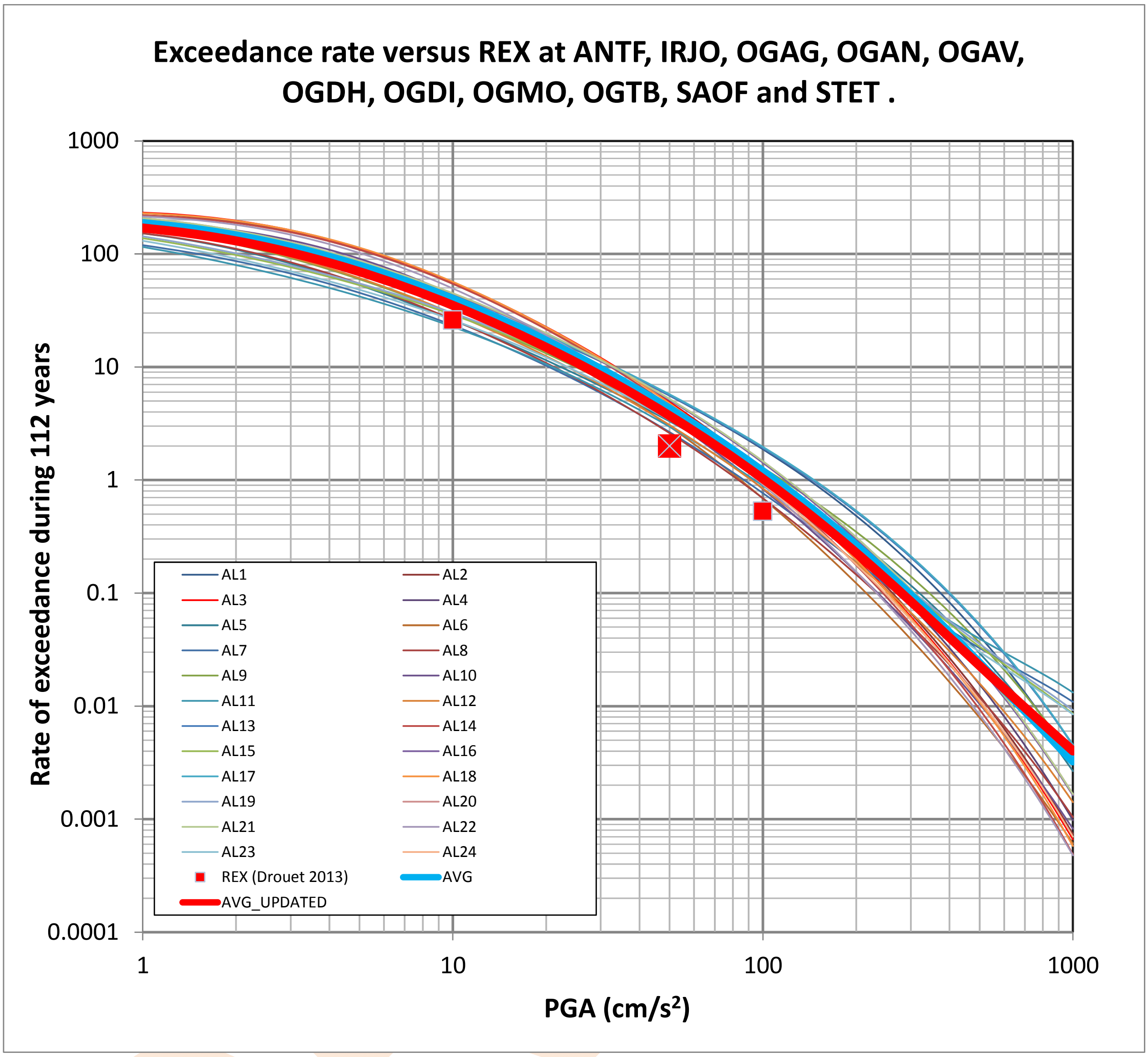


Figure 29. Test 15. Comparison of exceedance rate during the working period of the station and the historical REX. Set of 11 stations.

PGA (cm/s^2)	Prior					Posterior				
	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
ANTF	18	46	68	150	202	17	45	66	144	194
IRJO	24	67	98	203	265	21	59	87	182	238
OGAG	26	67	97	204	271	25	64	93	196	261
OGAN	25	68	102	225	305	24	64	96	213	293
OGAV	23	60	86	177	230	20	54	79	163	214
OGDH	23	63	95	211	283	22	61	91	201	271
OGDI	24	62	91	195	261	23	59	87	188	251
OGMO	26	65	94	196	258	25	62	90	191	253
OGTB	27	71	105	226	303	26	67	99	214	288
SAOF	28	75	110	227	296	26	70	102	212	278
STET	27	71	103	217	287	26	67	98	208	275

Table 13. Mean PGA at different return periods, after the update of seismic hazard. Test 15.

UPDATE METHOD
TEST NAME : Test 15

GEOTER EDF

Test specifications

Files number : **24**
K value : **1.01**
Acceleration threshold (cm/s²) : **50.0**
REX (Exceedance number) : **2.000000**

Test properties
REX histo
M>=4.5
PGA>=50 cm/s2
Data>1850
Obs. Per.: 112
Droet2013

Source directory : *C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs*

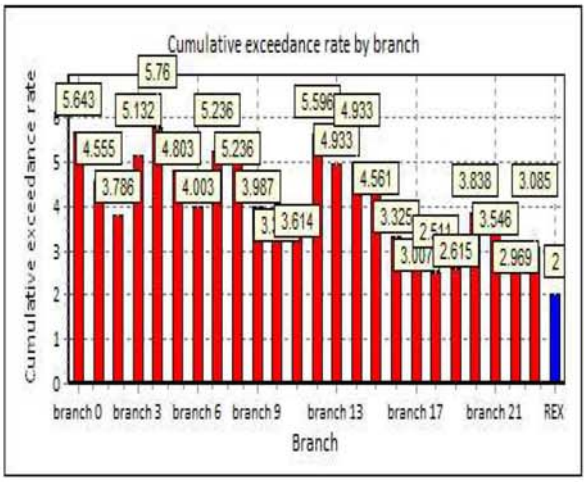
Sites - (11)

ANTF
IRJO
OGAG
OGAN
OGAV
OGDH
OGDI
OGMO
OGTB
SAOF
STET

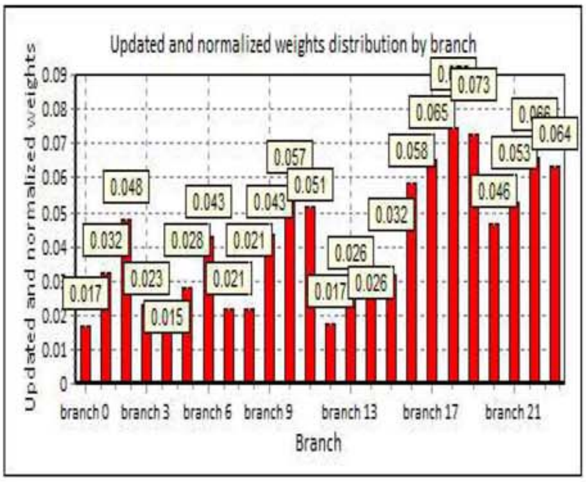
Main values

Mean exceedance rate a priori : **4.1692**
Updated rate : **3.7281**
Std deviation of exceedance rate a priori : **1.0061**
Updated std dev. : **0.8916**

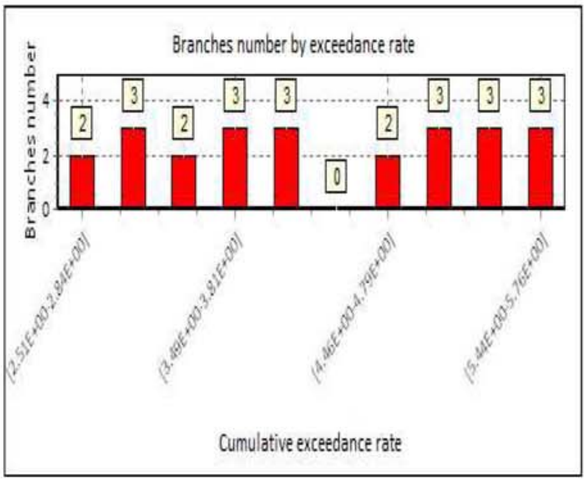
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

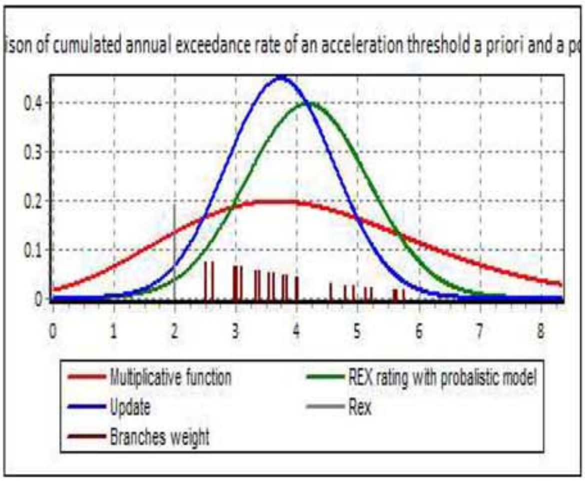


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Figure 30. Test 15. Updating of the seismic hazard considering REX historical, PGA level=10 cm/s2 and magnitude-PGA relation

6.4.7 Test 16: REX historical, PGA level=100 cm/s2 and Magnitude-PGA relation

The following test was performed using as input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 100 cm/s^2.
- Minimum magnitude: 4.5.
- Sites considered for analysis: ANTF, IRJO, OGAG, OGAN, OGAV, OGDH, OGDI, OGMO, OGTB; SAOF and STET.
- Period of completeness of station: 212 years (events from 1750 to 1962).
- REX: 1 (considering a historical period of stations, from 1750 to 1962). The acceleration values were obtained using Drouet 2013 ground motion prediction equation. Then, we obtained 1 exceedance of the acceleration level selected during the period of observation considered.

The Figure 31 shows the comparison between the cumulated *prior* and *posterior* mean exceedance rate. The Figure 31 includes also the cumulated exceedance rate predicted by each one of the 24 models used in this test.

The historical REX is equal to 1 (biggest red dot in Figure 31). For information purposes, the Figure 31 shows also the REX obtained using the same hypothesis except the acceleration threshold, which were fixed to 10 and 50 cm/s^2 (smaller red dots in Figure 31). They were used in tests 11 and 12.

In this case, the application of the updating method leads to a reduction of the mean seismic hazard. The *prior* and *posterior* mean curves are very close. This fact could be considered as normal because the predictive models are in a very good agreement with the REX. Therefore, the update of the seismic hazard is not necessary to get a better fitting between observations and predictions.

The Table 14 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard.

The analysis of Table 14 shows the same shown by Figure 31: the update of the seismic hazard decreases the mean exceedances of 100 cm/s^2 (global *prior* exceedance rate of 1.16 and *posterior* of 1.14, Figure 32). The decrease of the seismic hazard in the different sites is very weak (around 1%-2%) at 975, 5000 and 10000 years of return period (with accelerations near to 100 cm/s^2).

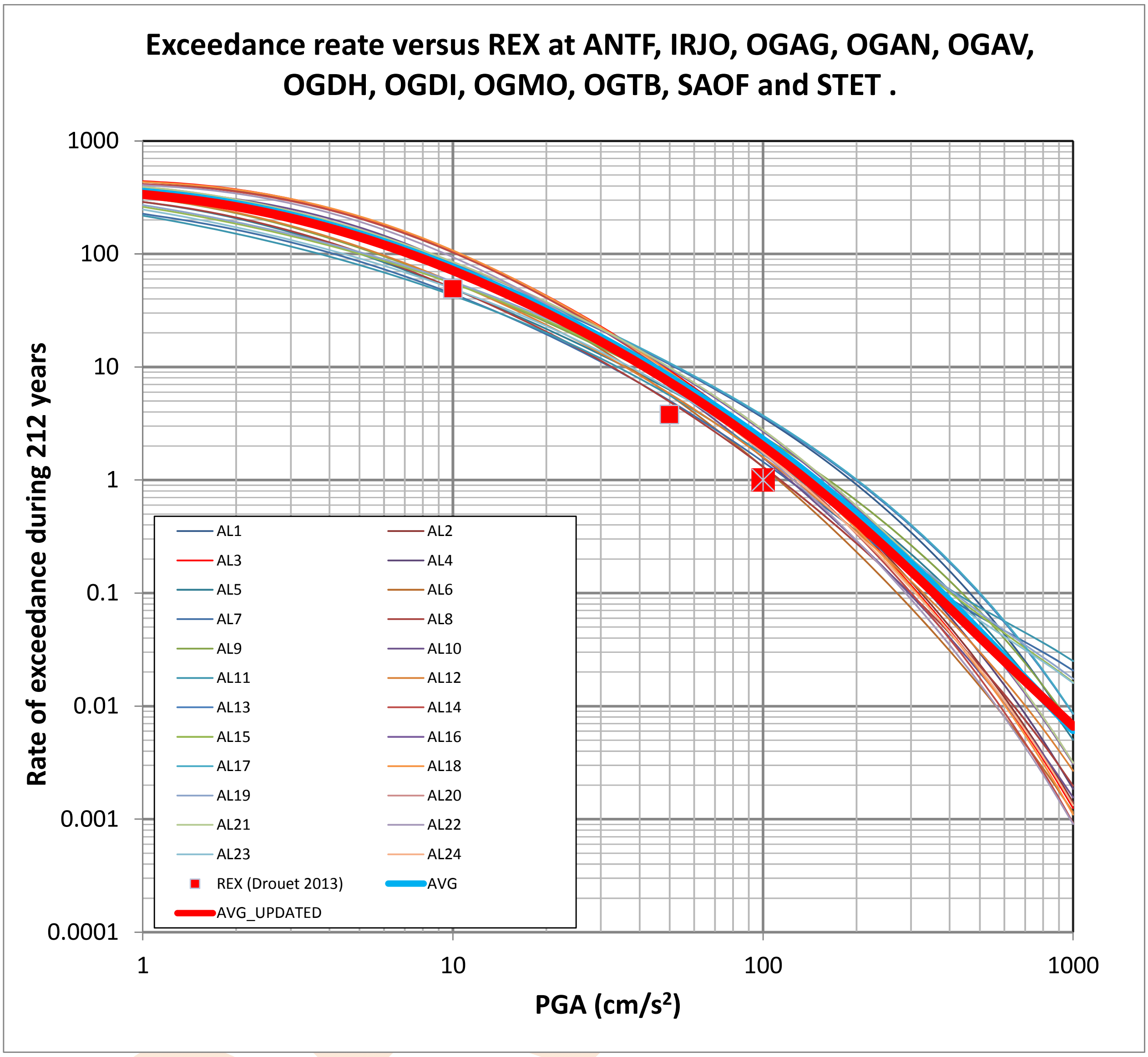


Figure 31. Test 16. Comparison of exceedance rate during the complete period of the stations and the historical REX. Set of 11 stations.

PGA (cm/s²)	Prior					Posterior				
	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
ANTF	18	46	68	150	202	17	45	66	143	192
IRJO	24	67	98	203	265	22	62	91	188	245
OGAG	26	67	97	204	271	26	65	93	194	258
OGAN	25	68	102	225	305	24	65	96	211	288
OGAV	23	60	86	177	230	22	57	82	168	219
OGDH	23	63	95	211	283	22	61	91	199	267
OGDI	24	62	91	195	261	23	60	87	186	248
OGMO	26	65	94	196	258	26	63	91	188	248
OGTB	27	71	105	226	303	26	68	100	213	286
SAOF	28	75	110	227	296	27	72	104	213	279
STET	27	71	103	217	287	27	68	99	207	272

Table 14. Mean PGA at different return periods, after the update of seismic hazard. Test 16.

UPDATE METHOD

TEST NAME : Test 16

GEOTER | EDF

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **100.0**

REX (Exceedance number) : **1.000000**

Test properties

REX_HISTO
M>=4.5
PGA>=50
Date: 1750
Per. fonc: 212
Drouet2013

Source directory : *C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs*

Sites - (11)

ANTF	OGDH
IRJO	OGDI
OGAG	OGMO
OGAN	OGTB
OGAV	SAOF
	STET

Main values

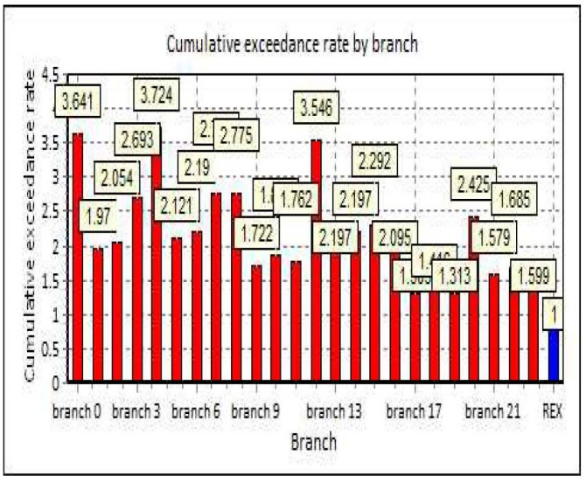
Mean exceedance rate a priori : **2.2051**

Updated rate : **1.9964**

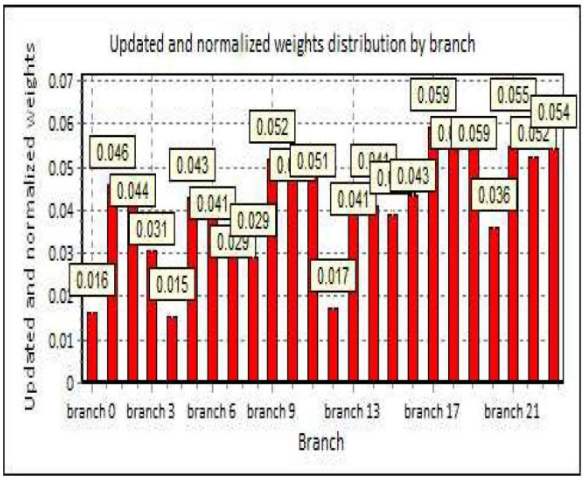
Std deviation of exceedance rate a priori : **0.6925**

Updated std dev. : **0.5467**

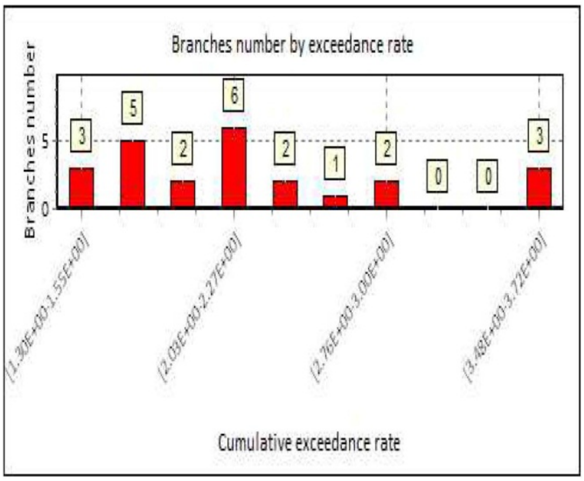
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

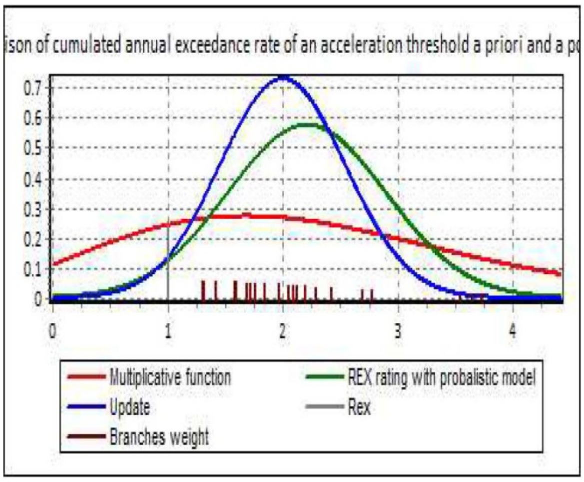


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Figure 32. Test 16. Updating of the seismic hazard considering REX historical, PGA level=100 cm/s2 and magnitude-PGA relation

6.4.8 Test 17: REX instrumental, PGA level=5 cm/s^2

The following test was performed using as input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 5 cm/s^2.
- Minimum magnitude: 4.5.
- Sites considered for analysis: ANTF, IRJO, OGAG, OGAN, OGAV, OGDH, OGDI, OGMO, OGTB; SAOF and STET.
- Period of completeness of station: the working period of each station.
- REX: 1 (considering the operational period of stations).

The Figure 33 shows the comparison between the cumulated *prior* and *posterior* mean exceedance rate. The Figure 33 includes also the cumulated exceedance rate predicted by each one of the 24 models used in this test.

The instrumental REX is equal to 1 (red dot in Figure 33).

The effects of the updating method are important at low acceleration values of the seismic hazard curves. The *posterior* mean curve is less penalizing. For high return periods (or high accelerations), the *prior* and *posterior* mean exceedance rates become almost equivalent.

The Table 15 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard.

The analysis of Table 15 shows that the update of the seismic hazard decreases the mean exceedances of 5 cm/s^2 (global *prior* exceedance rate of 7.07 and *posterior* of 4.63, Figure 33 and Figure 34). The decrease of the seismic hazard is not homogeneous and depends on the site, at 100 years of return period. At 10000 years of return period, the effect of the updating process leads to different results: sometimes we observe a decrease of seismic hazard (i.e. IRJO) and sometimes an increase of the seismic hazard (i.e. OGAN). Again, the effect of the updating process depends on the return period and depends on the site.

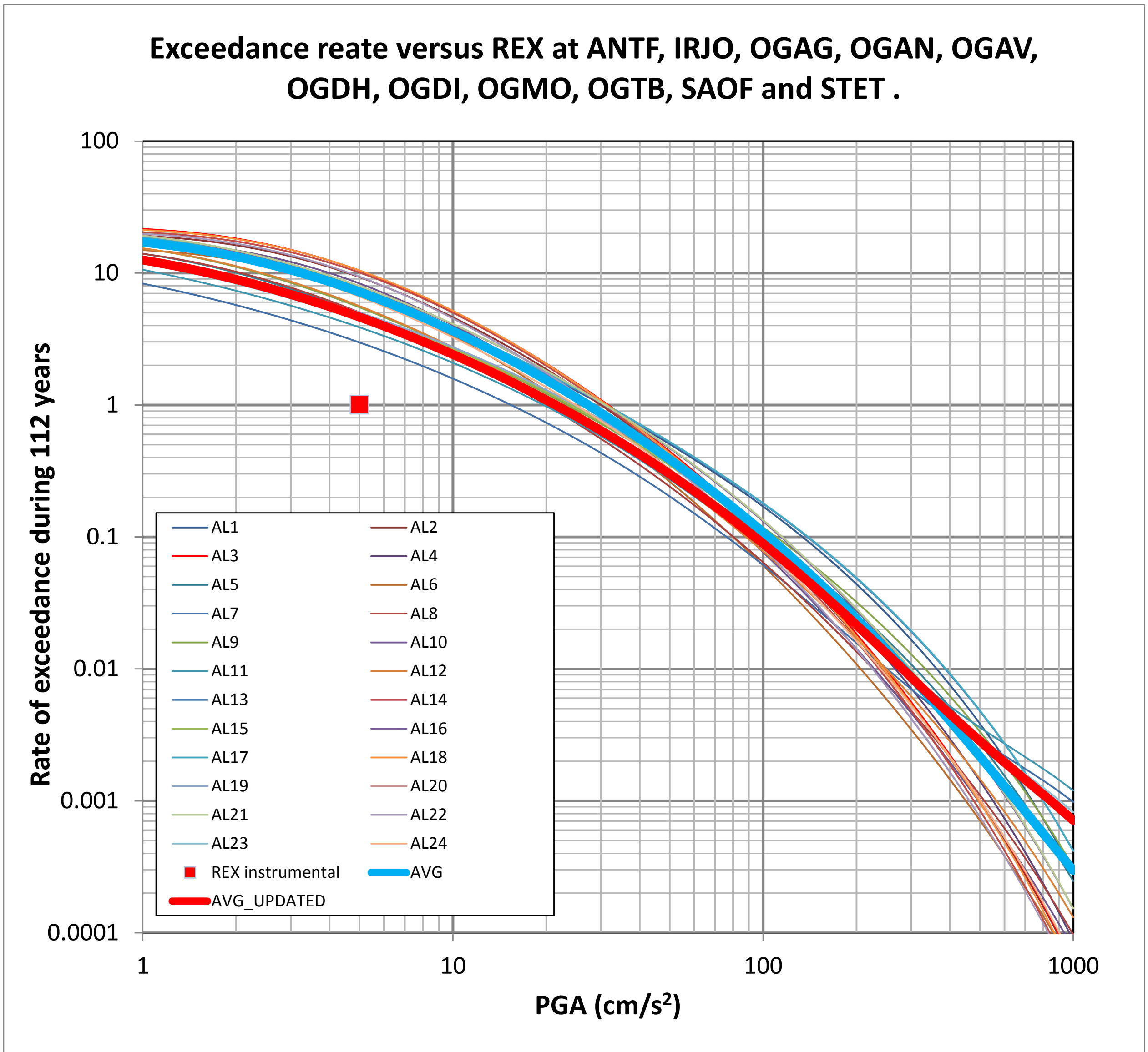


Figure 33. Test 17. Comparison of exceedance rate during the complete period of the stations and the instrumental REX. Set of 11 stations.

PGA (cm/s²)	Prior					Posterior				
	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
ANTF	18	46	68	150	202	14	42	64	146	200
IRJO	24	67	98	203	265	16	50	75	163	216
OGAG	26	67	97	204	271	22	61	91	200	274
OGAN	25	68	102	225	305	21	62	94	227	343
OGAV	23	60	86	177	230	15	45	68	149	199
OGDH	23	63	95	211	283	19	59	91	210	292
OGDI	24	62	91	195	261	19	56	85	194	264
OGMO	26	65	94	196	258	22	60	90	201	272
OGTB	27	71	105	226	303	22	64	97	220	303
SAOF	28	75	110	227	296	22	65	97	209	276
STET	27	71	103	217	287	22	63	95	214	291

Table 15. Mean PGA at different return periods, after the update of seismic hazard. Test 17.

UPDATE METHOD

TEST NAME : Test 17

GEOTER edf

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **5.0**

REX (Exceedance number) : **1.000000**

Test properties

REX instrumental

M>=4.5

PGA>=5

Source directory : C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs

Sites - (11)

ANTF, IRJO, OGAG, OGAN, OGAV, OGDH, OGDI, OGMO, OGTB, SAOF, STET

Main values

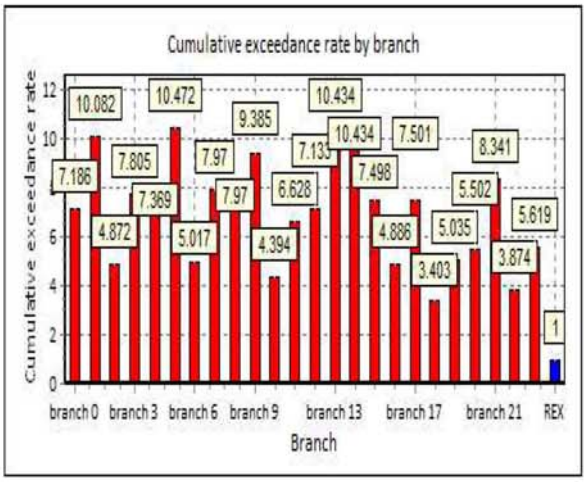
Mean exceedance rate a priori : **7.0337**

Updated rate : **4.6394**

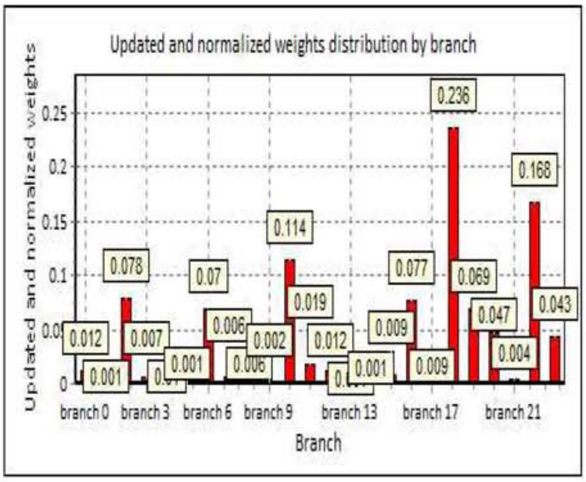
Std deviation of exceedance rate a priori : **2.1507**

Updated std dev. : **1.0983**

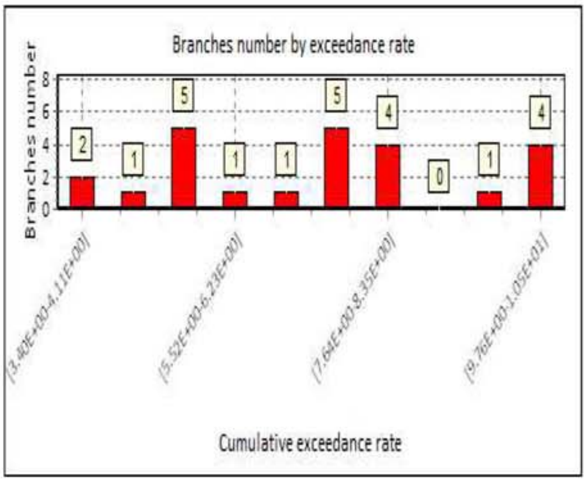
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

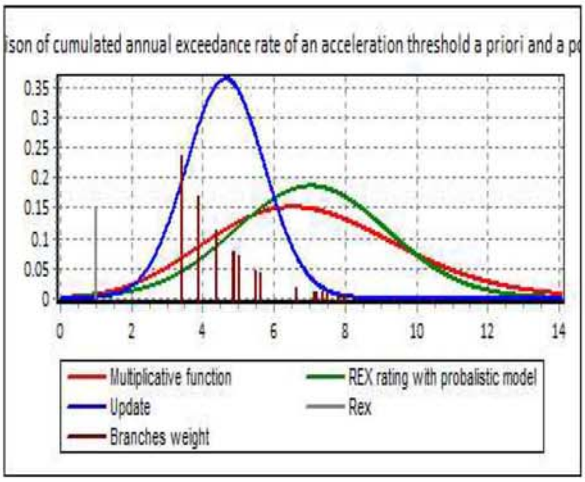


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Figure 34. Test 17. Updating of the seismic hazard considering REX instrumental, PGA level=5 cm/s2

6.4.9 Test 18: REX instrumental, PGA level=10 cm/s2

The following test was performed using as input data:

- Logic tree: the 24 main branches of the logic tree used in SIGMA (chapter 4).
- Threshold of acceleration: 10 cm/s^2.
- Minimum magnitude: 4.5.
- REX: 0 (considering the operational period of stations).
- Sites considered for analysis: ANTF, IRJO, OGAG, OGAN, OGAV, OGDH, OGDI, OGMO, OGTB; SAOF and STET.
- Period of completeness of station: the working period of each station.

The instrumental REX is equal to 0 (red dot in Figure 35 corresponds to 5 cm/s^2 threshold, used in test 14).

In this case, effects of the updating method are important at low acceleration values of the seismic hazard curves. The *posterior* mean curve is less penalizing. For high return periods (or high accelerations), the *prior* and *posterior* mean exceedance rates become almost equivalent and, finally, for very long return period the a posteriori exceedance rate is higher. Again, the effects of the updating process are not homogeneous for all range of accelerations.

The Table 16 shows the comparison of mean PGA obtained at different return periods, before and after the update of seismic hazard. The analysis of Table 16 shows that the update of the seismic hazard decreases the mean exceedances of 10 cm/s^2 (global *prior* exceedance rate of 3.54 and *posterior* of 2.71*,* Figure 35 *and* Figure 36). The decrease of the seismic hazard at 100 years of return period is general (10%-20% depending on the site).

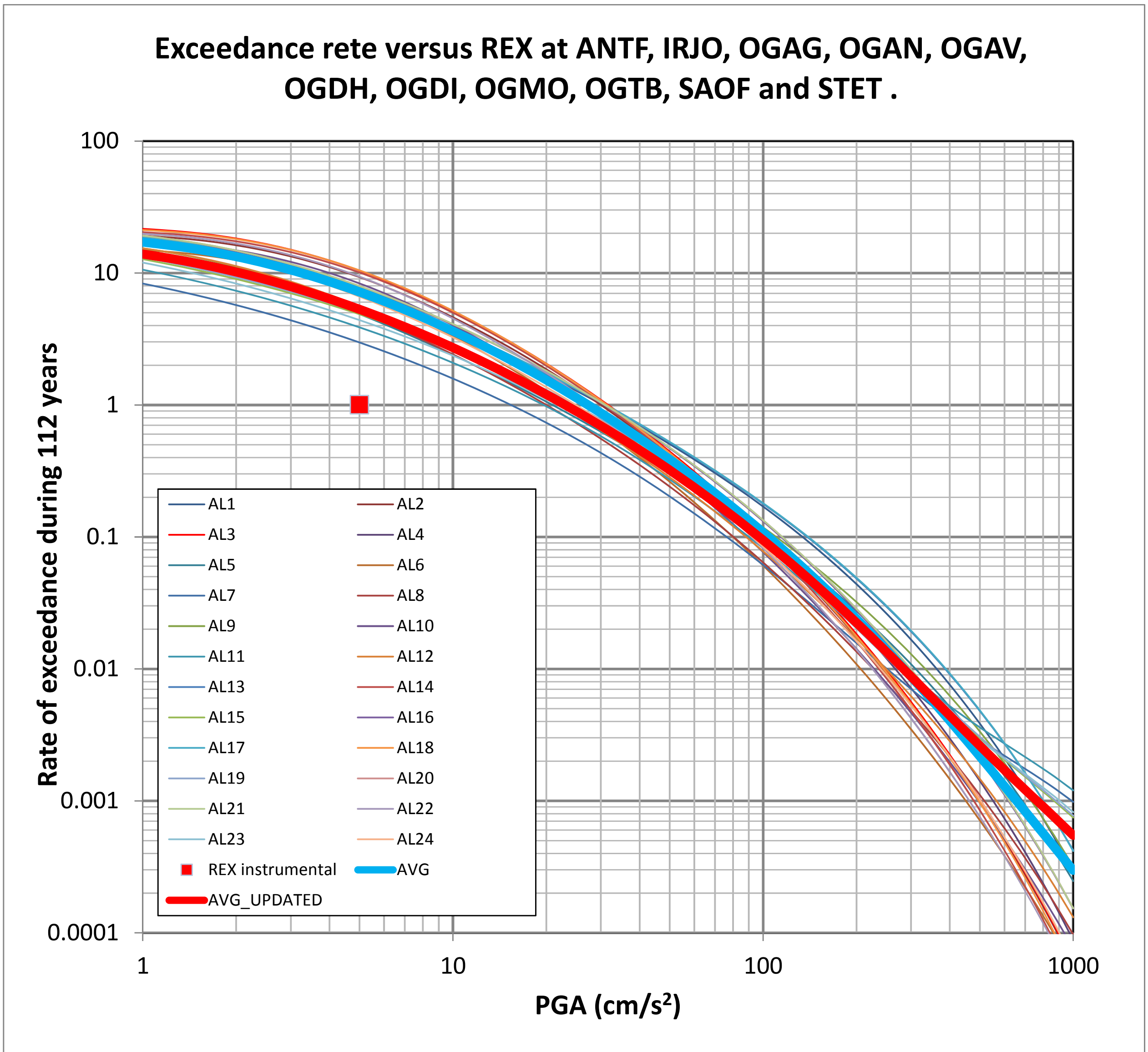


Figure 35. Test 18. Comparison of exceedance rate during the complete period of the stations and the instrumental REX. Set of 11 stations.

PGA (cm/s^2)	Prior					Posterior				
	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years	P=100 years	P=475 years	P=975 years	P=5000 years	P=10000 years
ANTF	18	46	68	150	202	15	43	65	148	202
IRJO	24	67	98	203	265	18	54	82	177	233
OGAG	26	67	97	204	271	23	63	93	203	276
OGAN	25	68	102	225	305	22	64	97	226	324
OGAV	23	60	86	177	230	17	49	74	159	210
OGDH	23	63	95	211	283	20	61	93	212	289
OGDI	24	62	91	195	261	21	58	87	196	265
OGMO	26	65	94	196	258	23	62	91	201	269
OGTB	27	71	105	226	303	24	66	99	222	304
SAOF	28	75	110	227	296	23	68	101	216	285
STET	27	71	103	217	287	24	66	98	216	291

Table 16. Mean PGA at different return periods, after the update of seismic hazard. Test 18.

UPDATE METHOD

TEST NAME : Test 18

GEOTER edf

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **10.0**

REX (Exceedance number) : **0.000000**

Test properties

REX instrumental

M>=4.5

PGA>=10

Source directory : C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs

Sites - (11)

ANTF	OGDH
IRJO	OGDI
OGAG	OGMO
OGAN	OGTB
OGAV	SAOF
	STET

Main values

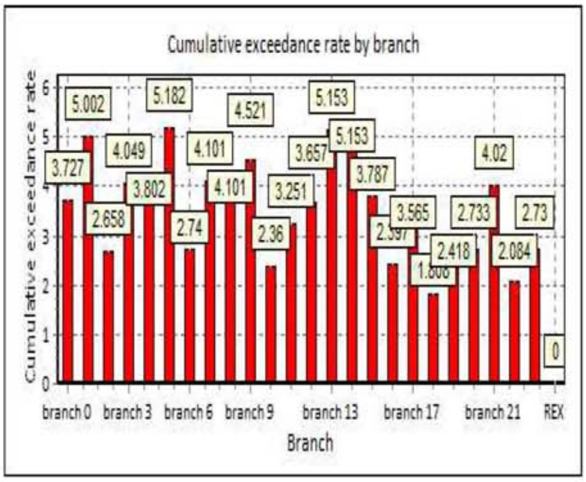
Mean exceedance rate a priori : **3.5416**

Std deviation of exceedance rate a priori : **1.0254**

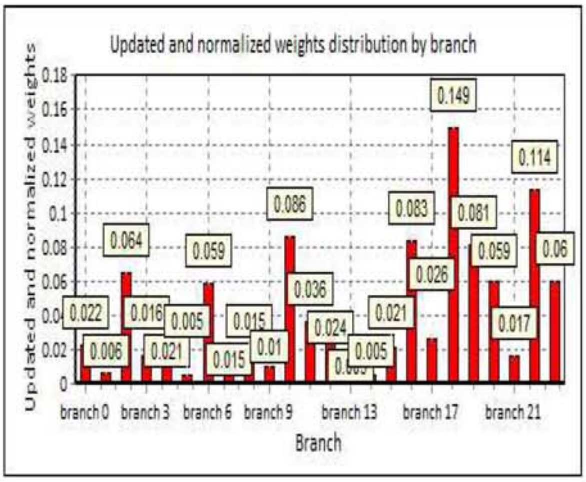
Updated rate : **2.7134**

Updated std dev. : **0.7452**

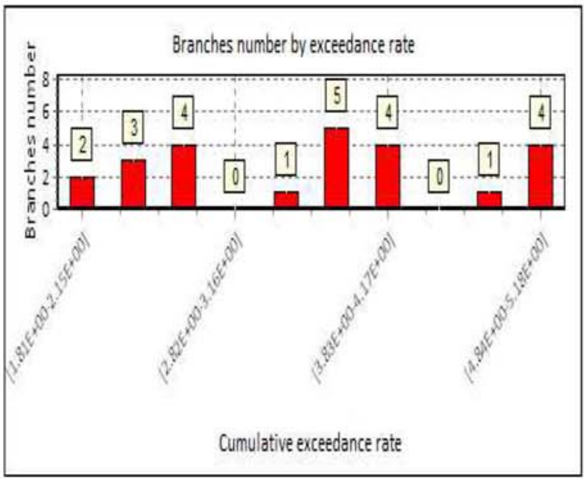
Cumulative exceedance rate by branch



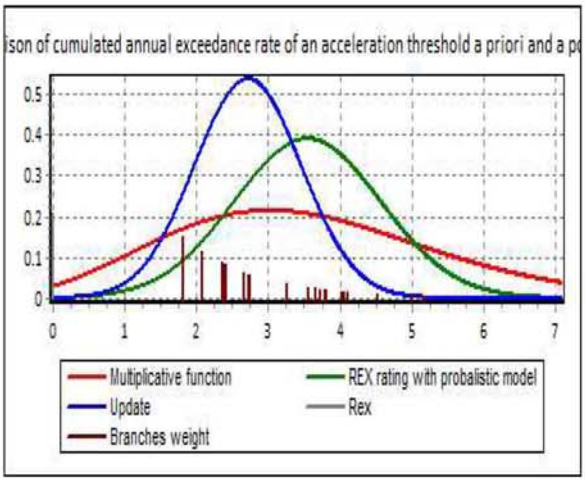
Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison



Bayac2014 *printed : 15/10/14 11:36:33* *Page 1/1*

Figure 36. Test 18. Updating of the seismic hazard considering REX instrumental, PGA level=5 cm/s2.

7. DISCUSSIONS AND CONCLUSIONS

The tests previously described (and other tests performed but not presented here) allow defining some basic rules to envision an application of the Bayesian updating method to the PSHA. The method is justified from the mathematical point of view. It provides an objective way to define the weights of the different branches of the logic tree instead of using the common and subjective methodology based on expert judgment. The method can be applied in all cases and there are no mathematical constraints. The application of the method offers the possibility to use the data specific to the region and to decrease the uncertainties. They are, however, limitations in its application and we have to keep in mind constraints due to each context in which it is intended to be applied.

Globally, the effect of the Bayesian updating method is to give a higher weight to the probabilistic models that predicts exceedance rates closer to the observed data (REX) and a lower weight to the probabilistic models predicting exceedance rates far from the observed data.

Therefore, the global effect of the Bayesian updating process is to bring closer the predictive probabilistic model to the recorded (or estimated) data (REX).

The main rules to take into account during the application of the Bayesian updating method are the following:

1) **Logic tree**: The selection of the logic tree is a key point. ***In an ideal case, the observed or estimated REX should be into the range of predictions of the probabilistic model (number of exceedances of a threshold of acceleration in a certain period of observation)***. In that case, when the uncertainties of the predictive model cover the REX, the updating method is more effective.

2) **Number of sites**: When the REX is composed by more than 1 site and the updating process is applied to update the seismic hazard at more than 1 site, the effects of the updating process could not be equivalent at all sites. At each site, the shape of the seismic hazard is different and the *posterior* weights have not the same effects for all seismic hazard curves. ***In an ideal case, we should use the REX of only 1 station to update the seismic hazard at the same site***. However, this is almost impossible in regions with low activity, due to the poor recorded accelerometric samples. When the consideration of more than 1 site is necessary, the recording sites should belong to the same seismotectonic context and be statistically independent.

3) **REX**: The number of observations (exceedances of a fixed acceleration level during a period of time) is important. Preferably, it should be highest as possible because the updating process is more effective. ***The REX should be as rich as possible and cover all ranges of accelerations***. Nevertheless, if the selected threshold of acceleration is high, the number of exceedances of this acceleration will be low. Besides, even if the REX is zero, this zero is some important information and the Bayesian updating process is able to take into account 0 exceedance. It is not strictly the same to have 0 exceedance in 10 years than not to have observations.

4) **K parameter**: This parameter is related to the correlation among stations. If the parameter is close to 1 (assuming no correlation among stations) the effect of the updating process is higher. Ideally, the best option should be the use of independent stations for updating purposes. In this case, the effect of the Bayesian updating process in more effective. ***K should be as close as possible to 1***.

5) **Period of observations**: Greater the period of observation, higher the effect of the updating method. If the period of observation is very short (i.e. only instrumental period for only few stations) the effects of the updating method are not significant. The use of the historical REX, even if it is a synthetic REX, improves the

effects of the Bayesian updating process and offers the possibility to update the whole hazard curve. ***The period of observation should be as long as possible***.

6) **The threshold of acceleration** used for the updating process. The updating process is always performed using a pre-defined acceleration threshold. Then, the results of the updating process are well defined or adapted for the accelerations of the seismic hazard curve near to the considered acceleration threshold. For example, to use the weights of the different branches of the logic tree defined with a Bayesian update and an acceleration threshold of 10 cm/s^2 to update the seismic hazard at high return periods (associated to high acceleration values) seems to be in the limits of the applicability of the method. ***The level of the acceleration thresholds used should preferably be in agreement with the accelerations associated to the return periods of analyse***.

The Bayesian updating process could be performed, at a same site, using different hypothesis: different acceleration thresholds, different type of REX (observed and estimated). The estimated REX could be generated using different approaches that also take into account the uncertainties, etc. These epistemic uncertainties could be treated also using the logic tree methodology. The different weights obtained with different updating hypothesis for the same branch of the logic tree, could be used to calculate a mean weight of the logic tree ($\overline{W_i}$.). The mean weights of the branches of the logic tree could be used to finally get the updated mean, median and centiles 16% and 84% seismic hazard curves.

The Table 17 shows some rules that could be used to update the seismic hazard.

Subject	Basic rules to consider
Logic tree	1. Ideally, the REX (observed or estimated number of exceedances of an acceleration threshold) should be situated in the range of uncertainties of predictive models possible predictions. 2. In that case, the updating method is effective. .
K parameter	1. K is the average number of sites impacted by one earthquake. 2. It should be calculated by each threshold of acceleration and for each selection of sites. 3. The ideal case, when the updating method is more effective, is when K=1 (independence of stations)
Period of observation	1. It should be as long as possible. If the period of observation is too short, the effect of updating process is negligible 2. The instrumental REX is more reliable (recorded data), but the period of observation is short 3. If it is possible, the use of historical REX, with a longer observation period, is recommended.
Threshold acceleration	1. The threshold of acceleration selected for updating purposes should be chosen as close as possible to the acceleration levels of interest. 2. The impact of the updating process using different acceleration thresholds could be different.
REX	1. If possible, it is recommended to use threshold of accelerations and periods of observations with some observations (REX>>1). In these cases, the comparison is possible. 2. However, even if the number of observations (REX) is zero, it is also an important information and the Bayesian updating process is able to take into account.
Treatment of uncertainty in the updating process	1. Depending on the hypothesis considered (acceleration threshold, selection of sites, REX considered, etc.) several updating process and, therefore, different weights of each branch of the logic tree will be obtained. 2. The uncertainty in the updating process could be also taken into account. For example, a simple process should consist on calculating the mean weight, $\overline{W_i}$.

Table 17. Main rules to be considered during the application of the Bayesian updating process.

The effects of the Bayesian updating methods will be more important when the predictions of the different branches of the logic tree are very different. In the SIGMA logic tree selected for these exercises, the differences between the predictions of the different branches of the logic tree were not significantly different. For that reason, the effects of the updating process are limited.

Nevertheless, when we consider high acceleration threshold in the updating method (i.e. 0.2 g in test 13), we obtain a reduction of 10% of the seismic hazard at a return period of 10000 years.

The Bayesian updating process could be a useful tool to define more objectively the weights of the different branches of a logic tree. The methodology can be easily implemented as soon as the REX database is available. It offers a different approach to define the weights of a logic tree. This alternative approach could be explored and used for practical applications.

To envision a practical application (complementary to sensitivity analysis), the Bayesian update could be applied to more seismic active regions. A simple test could be to use the logic tree developed in the SHARE program as a prior PSHA and the RESORCE database to generate the REX

Besides, the updating method could be applied in the spectral acceleration domain and not only to the PGA. It would allow appreciating the variability of weights in the spectral domain and an update of a full response spectra. It means, the same methodology could be applied comparing the recorded spectral acceleration to the spectral accelerations predicted by a PSHA.

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9. ANNEX 1: PRESENTATION OF THE SOFTWARE DEVELOPED FOR APPLICATION OF BAYESIAN UPDATING

The software developed is based in that developed in 2008 (Martin et al. 2008). The new software developed during this project includes the main functions developed in 2008 and incorporates some new capabilities.

The new software is called *Bayac14.* The main interface (Figure 37) allows to access to 2 basic interfaces:

- *Analyze and complete REX file*: Interface to read the global REX and to treat statistically it (adopting for example some filters, to create partial REX databases depending on the filters, relations to convert intensity to PGA, etc.)
- *Bayesian update*: Interface to update the seismic hazard using, as input data, the prior probabilistic models of a logic tree (that can be loaded by the user) and a REX defined by user.

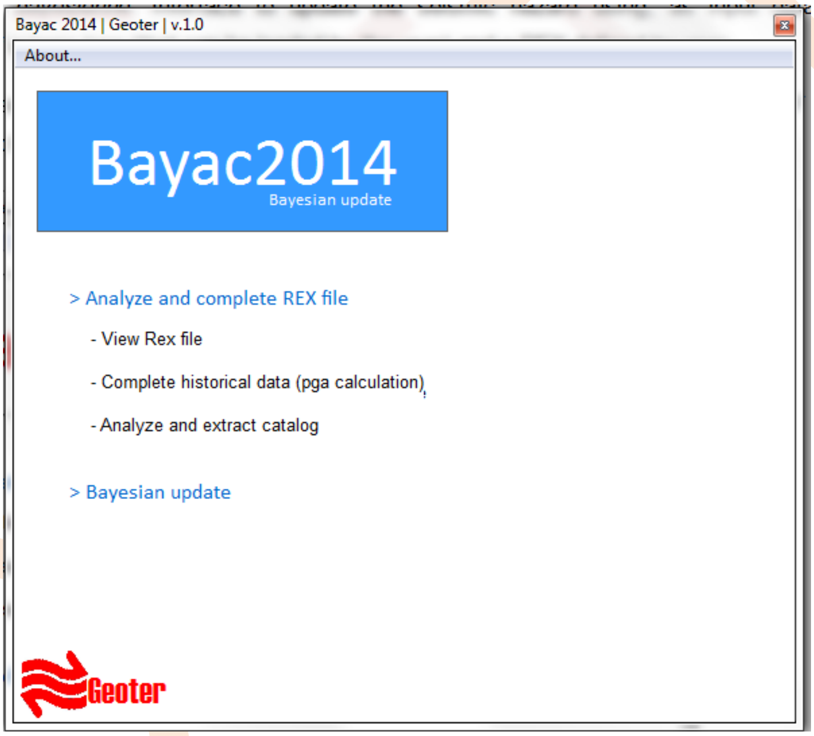


Figure 37. Main interface of Bayac14 software.

9.1 INTERFACE TO ANALYZE THE REX

9.1.1 Loading the REX

The first interface of Bayac14 allows loading the global REX, defined with the format fixed in chapter 5. The instrumental REX defined for this project contains 965 records. The historical REX developed for this project contains 12549 records.

Both REX databases can be treated statistically, filtered and the results could be saved to generate partial REX (it means, the number of exceedances of a defined acceleration threshold in a certain number of sites). The partial REX is used in the Bayesian updating process.

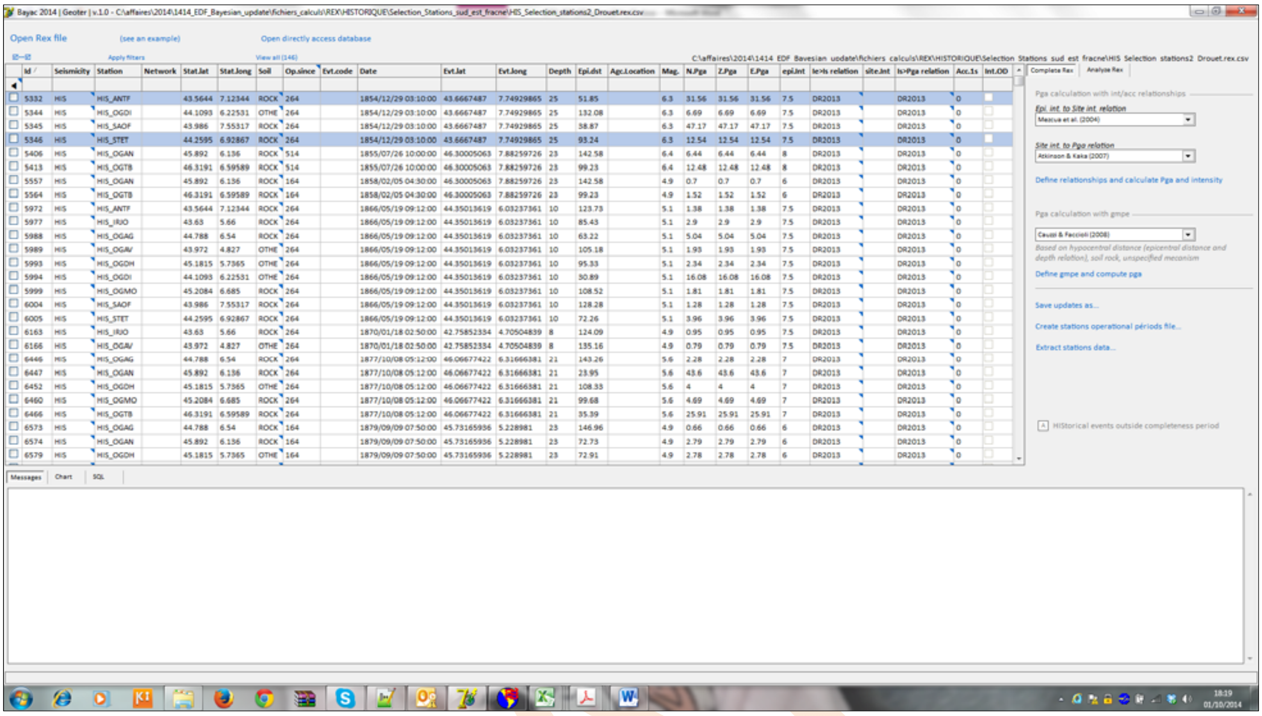


Figure 38. Interface of treatment of a REX database.

9.1.2 Filtering of REX

The software offers to the user different possibilities to filter the original REX:

- ➢ The filter could be done using SQL sentences (Figure 39)
- ➢ The filter can be done introducing the filter condition in a box (Figure 39).
- ➢ The filter can be done using a selection performed using the mouse.

When the different filters are defined, the user can execute them. Automatically, a filtered REX is generated and it can be saved in order to keep the partial REX generated using these filters. Several filters can be applied at the same time. For example, a partial REX could be, for instance, generated using an acceleration threshold 20 cm/s^2, in the SAOF station, produced by earthquakes with magnitude equal or greater than 4.5.

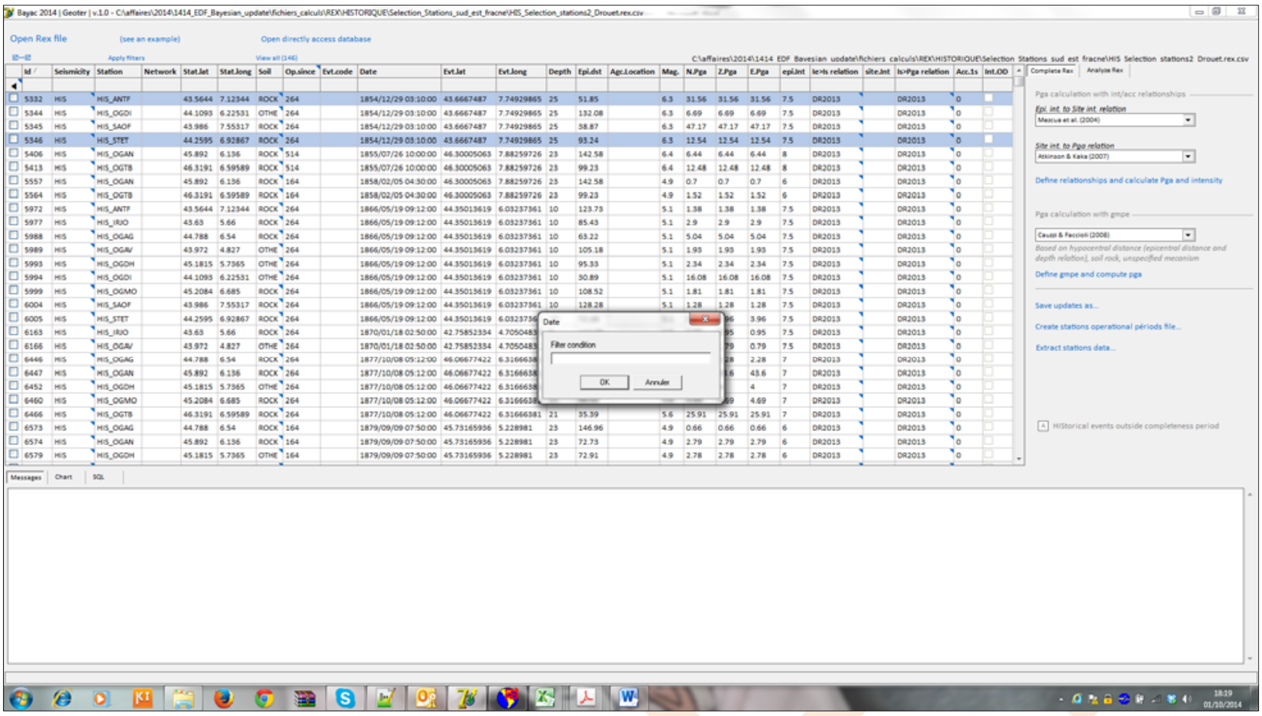


Figure 39. Example of filtering of REX.

9.1.3 Relations Io-Isite, Isite-PGA and Magnitude-Distance-PGA relations

When we work with an original and non-treated historical REX, normally, the epicentral intensity is indicated for each record. However, the punctual intensities probably felt at the site are not indicated. They can be calculated selecting the intensity prediction equation. 15 possibilities are introduced by default in the software. 14 of them are associated to the attenuation of the intensity (Figure 40) in different regions of France (the *Rhin, Alps, Provence, Massif Armorcaine, North of France, Pyrenees, other regions* of France (Martin et al. 2008). The last one is the relation proposed by Mezcua et al. 2004.

The PGA probably felt at the site can also be calculated using 6 relations defined by default in the software: Gomez & Capera 2007, Regles PS92, Panza et al. 1997, Decanini et al 1995, Faccioli and Cauzzi 2006 and Atkinson & Kaka, 2007).

The PGA can also be calculated using the ground motion prediction equation defined by Drouet (2013) in terms of epicentral distance. This GMPE uses the distance from the site to the epicenter and the magnitude in order to define the PGA. The PGA could be calculated also using the GMPE of Cauzzi & Faccioli (2008), defined in terms of hypocentral distance.

When the PGAs are defined, the REX could be filtered (i.e. defining a minimum magnitude, the period of completeness, or a threshold of PGA) in order to define the REX to be used to update the seismic hazard.

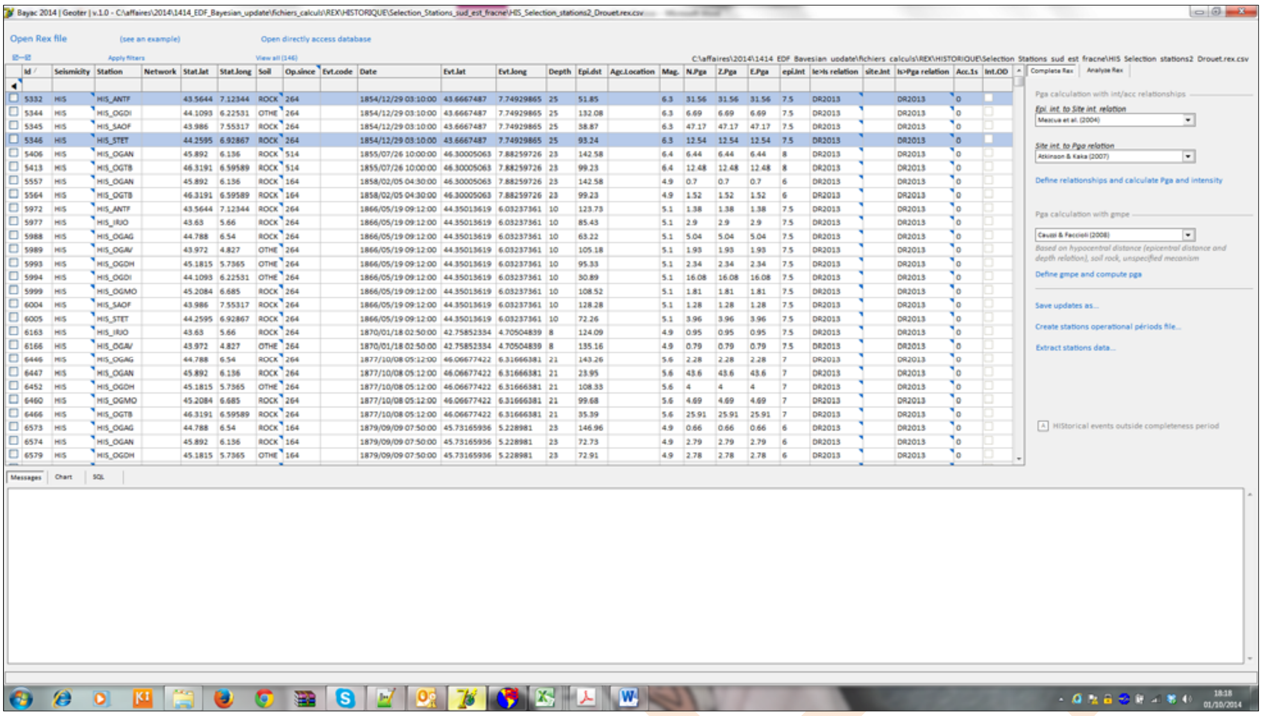


Figure 40. Interface of treatment of a REX database. Intensity prediction equation.

9.2 INTERFACE TO UPDATE THE PSHA

This interface helps to define all input data needed for the Bayesian updating process. To summarize, the input data needed to perform a Bayesian updating consist on a set of probabilistic models (logic tree of a PSHA) and a REX. The probabilistic models should contain the seismic hazard curves at the sites where the predictions of the seismic hazard will be compared to the REX. The REX consists on the calculation of the observed (or estimated) number of exceedances of a threshold of acceleration in the selected sites. The Figure 41 shows an example of seismic hazard curves in a site compared with the REX calculated using 2 threshold of acceleration.

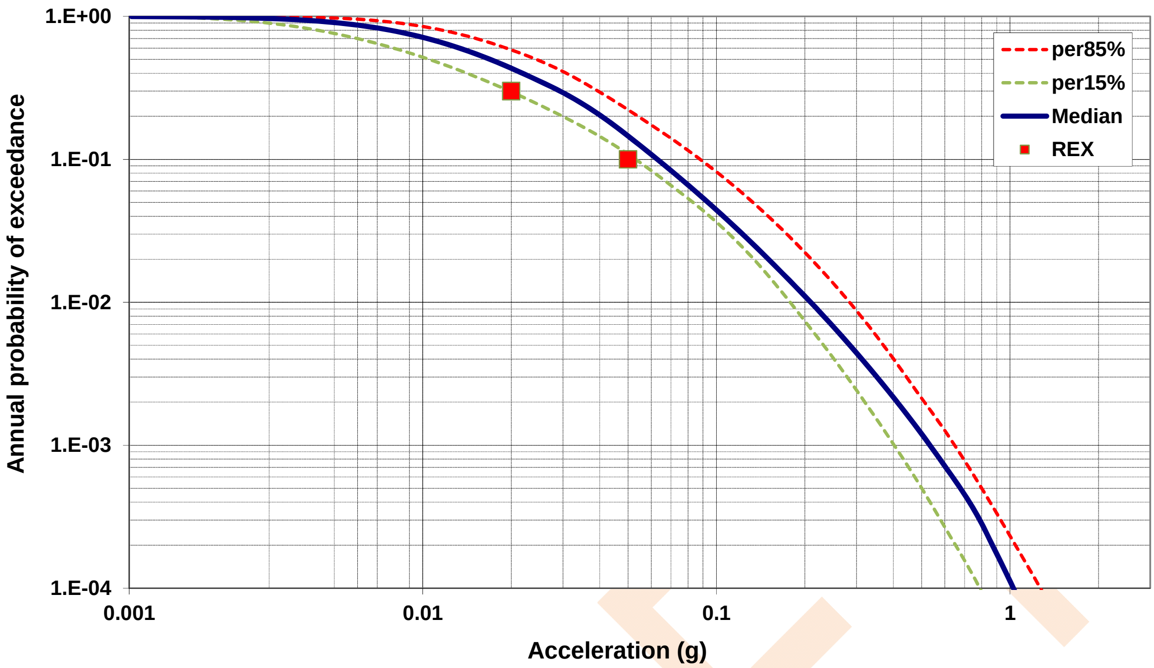


Figure 41. Comparison of the predictions of a seismic hazard curve and a REX, for 2 acceleration levels..

This interface (Figure 42) allows to the user the selection of the different input information:

- **K value**: This value is related to the correlation among stations. If the stations are independent (1 earthquake is associated to an exceedance of the threshold of acceleration in only 1 station) k value is equal to 1. If there is some correlation among stations (1 earthquake is associated to the exceedance the acceleration threshold in some stations) K is greater than 1 (Figure 42). K is the average number of sites impacted by one earthquake.
- **Threshold of acceleration**: It corresponds to the PGA threshold used to count the number of exceedances of PGA in the selected sites during the period of observation (Figure 42).
- **REX** (number of exceedances): It corresponds to the global number of exceedances of the threshold of acceleration defined previously (Figure 42), at the sites of analysis.
- **Logic tree**: The user can select the logic tree desired. It should be defined using *.gra files (files containing the seismic hazard curves at different sites) with different Crisis formats (Figure 42). When the Crisis files are selected, a box shows the sites where the seismic hazard curves are calculated in the Crisis file. Then, the user can select the sites that he would like to use in the updating process. Of course, the number of sites used to define the REX must be in agreement with the sites selected.
- **Period of observation of stations**: The observation periods of the different stations should be defined in a separated file. It will be select by the user (Figure 42).
- **Ratios interaction soil-structure**: This file contains the ration between the acceleration recorded in free field and the acceleration recorded in the structure of a building. If this file is not indicated, all ratios for all stations are supposed to be 1. This parameter was introduced to take into account the acceleration recorded

in NPPs sites. In those facilities, the strong-motion recorders are normally situated inside the buildings and they are not in the free field. This file allows converting the strong motion recorded in the buildings into free field ground motion.

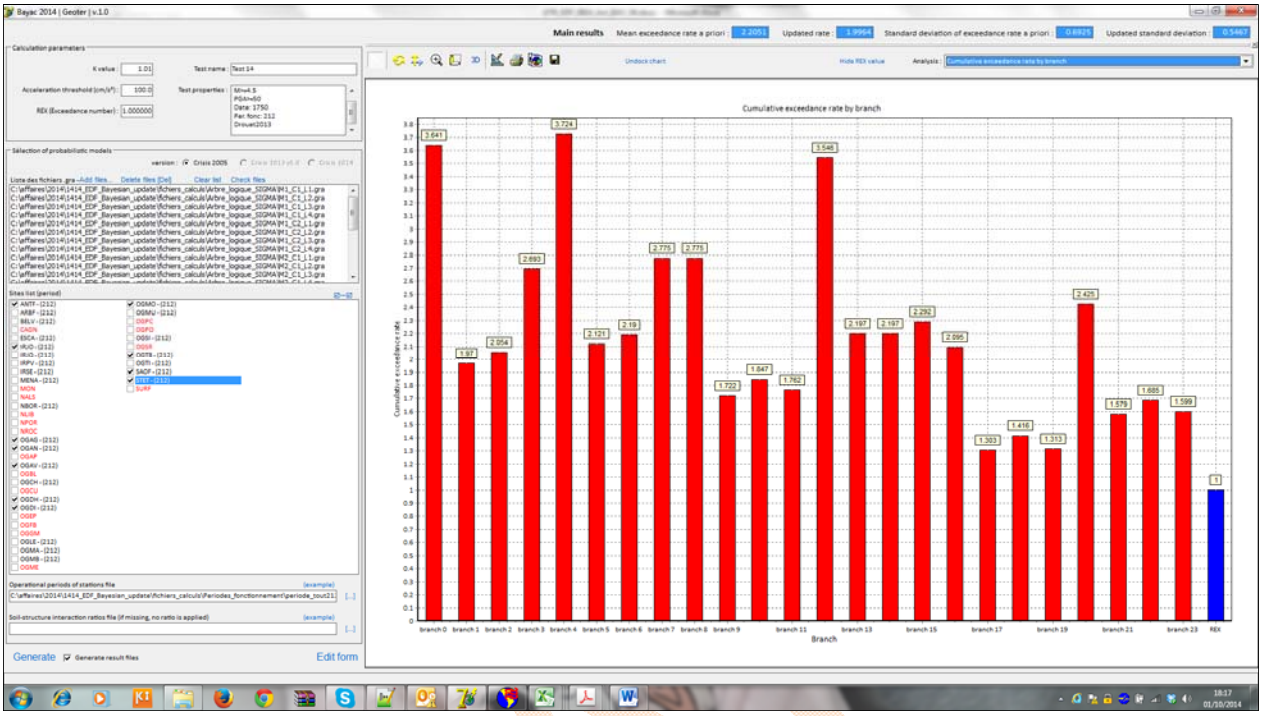


Figure 42. Interface to update the PSHA using a Bayesian approach.

The prior weights supposed for the logic tree considered are always equivalent. It means that the original *a priori* weight is always 1/N, being N the total number of branches of the logic tree considered.

After the definition of input data, the user can calculate the *posterior* weights of the different branches of the logic tree using the button "*Generate". The output files will be saved if the option "*Generate results files*" is checked.

After finishing the calculations, the user has the possibility to see 4 different types of plots:

- A plot showing the global number of exceedances of the PGA threshold during the period of observation of the stations predicted by the N branches of the logic tree (red bars) compared to the REX (blue bar) (Figure 43).
- A plot showing number of branches of the logic tree predicting an interval of exceedances (Figure 44). This plot allows to analyze the shape of the exceedance rate distribution (i.e. if the distribution has a Gaussian shape or a uniform shape, if there are some models very biased from the median, etc.).
- A plot showing the posterior weights of the different branches of the logic tree (Figure 45). The addition of all weights is 1. It means that the weights are normalized (equation 10)
- A plot showing the comparison between the Gaussian distribution of the global number of exceedances of the selected level of acceleration in the selected sites predicted by the *prior* model and by the *posterior* model (Figure 46). In Figure 46, the green line represents the Gaussian distribution of the distribution of *a prior* exceedance rates. The blue line represents the Gaussian distribution of the distribution of *a posterior* exceedance rates. The brown bars represent, in axis, the number of exceedances predicted by each one of the branches of the logic tree. The brawn bars also represent, in ordinates, the *posterior* weight of the different branches of the logic tree (taller is the bar, higher is the weight of the branch)

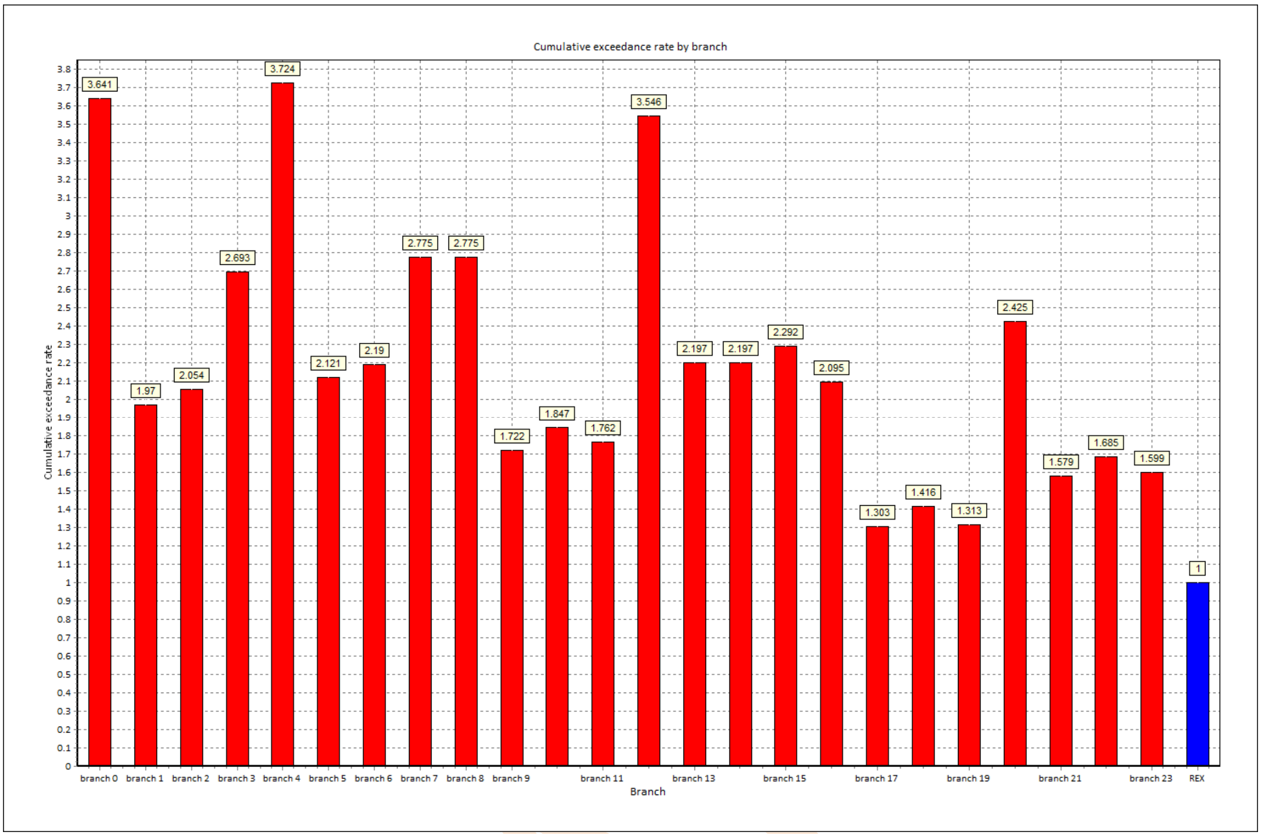


Figure 43. Plot showing the comparison between predicted exceedances rates of the N branches of a logic tree and the observed REX.

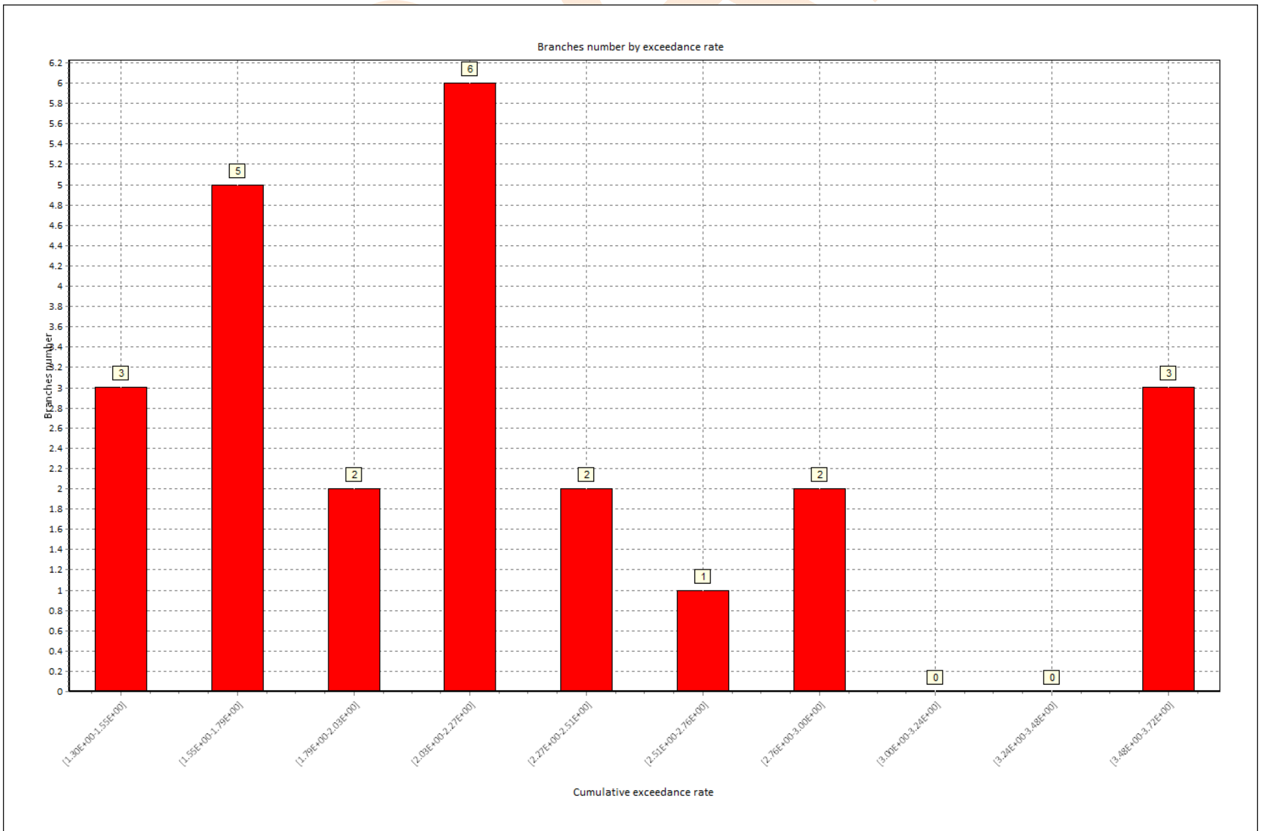


Figure 44. Plot showing the number of branches of the logic tree predicting a range of exceedances.

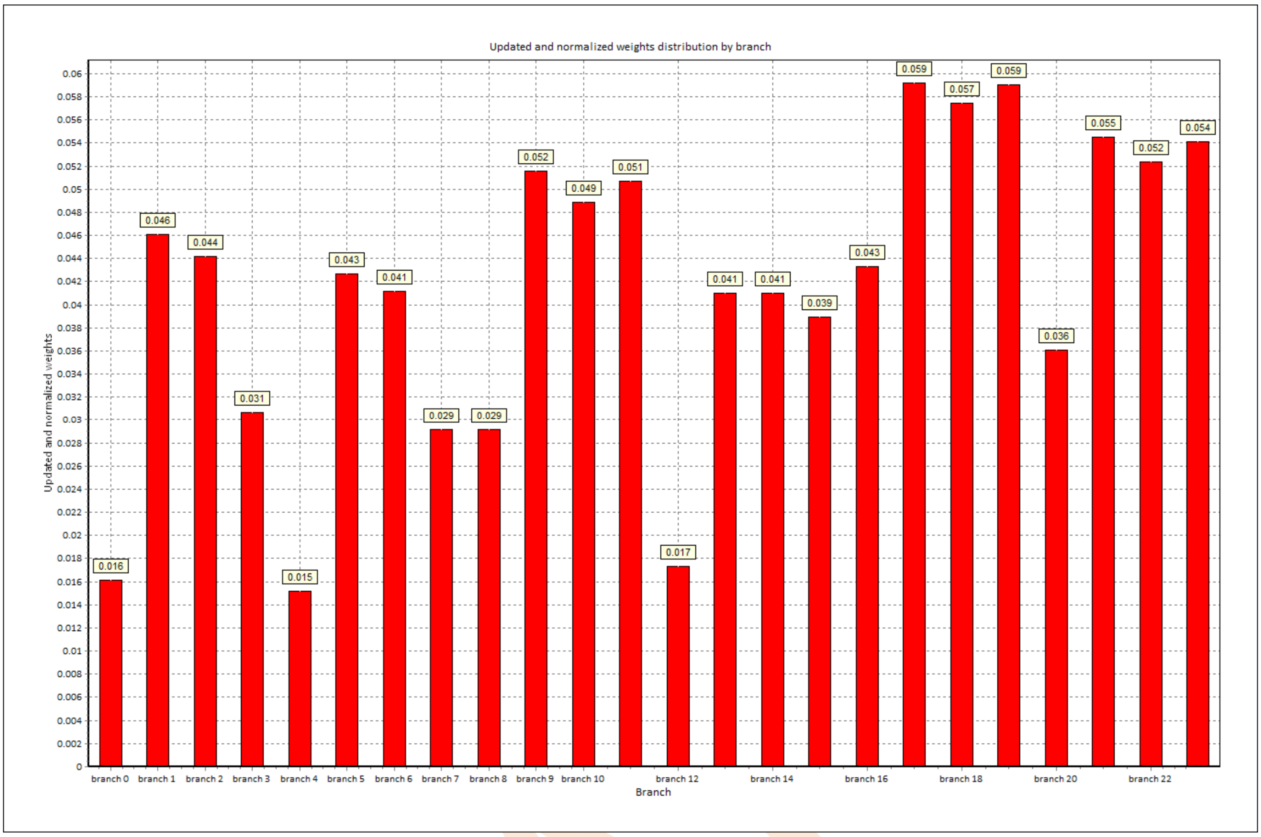


Figure 45. Plot showing the weights of the N branches of the logic tree.

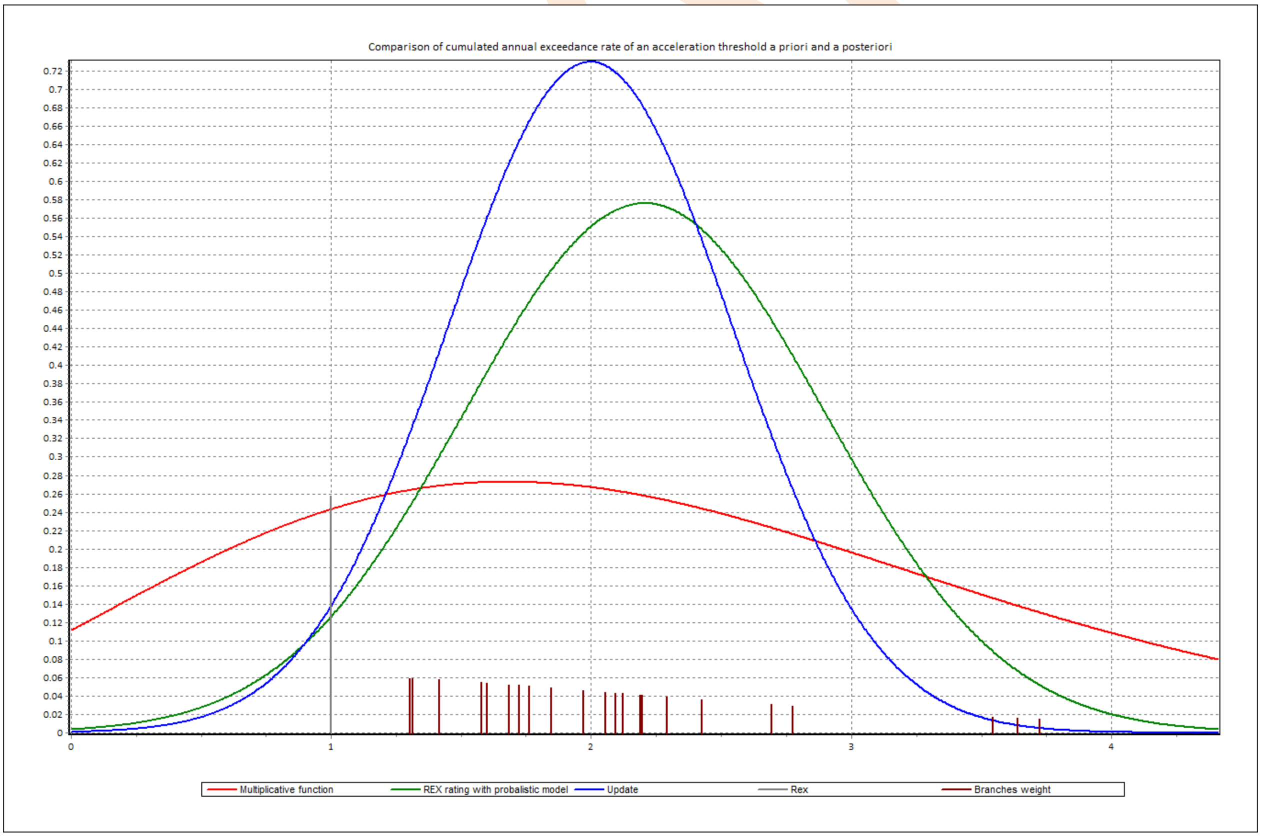


Figure 46. Plot showing the comparison between the Gaussian distribution of the global number of exceedances in the selected sites predicted by the a priori model and by the a posteriori model

Finally, the user have the possibility to create a pdf file containing a summary of the updating process performed (Figure 47). This pdf file contains the following information:

- **Input data (**Test specifications frame**)**:
  - Files number: Number of branches of the logic tree
  - K value
  - Acceleration threshold used
  - REX (number of exceedances of the acceleration threshold during the period of observation)
  - Sites used to define the REX (Sites frame). They are indicated in the box “sites” of the pdf file
- **Output data (**Main values frame**)**:
  - Prior mean exceedance rate: Each branch of the logic tree predicts a number of exceedances of the acceleration threshold during its observation period in the sites selected. The mean exceedance rate a priori corresponds to the mean of the N predictions.
  - Standard deviation of prior exceedance rate: it corresponds to the standard deviation of the distribution of N prior exceedance rates. This value indicated the uncertainty in the predictions.
  - Updated rate: It corresponds to the weighted or posterior mean exceedance rate of the N predictions, considering the updated weights of each branch of the logic tree. Comparing the updated rate with the mean prior exceedance rate, we have a global image about the impact of the updating process.
  - Standard deviation of posterior exceedance rate: it corresponds to the standard deviation of posterior distribution of exceedance rates. The comparison of prior and posterior standard deviations of the exceedance rates gives a global image about the increase/reduction of the uncertainty.
- **Plots:**
  - Cumulative exceedance rate of each branch (Figure 43).
  - Updated weights of each branch (Figure 44)
  - Cumulative exceedance rate distribution (Figure 45)
  - Prior-posterior comparison (Figure 46)

The output data provided by the software are the following:

- **date_heure_poids.csv**: This file contains the following fields of information (columns) for each of the probabilistic models included in the updating process:
  - The name of the probabilistic model (FICHIER) and the folder where it is situated (i.e. C:\……\model1.dat.)
  - The name of the recording station (CO_STATION)
  - The period of completeness of the seismic station (PER_FONCTIONNEMENT)
  - The PGA threshold used (SEUIL_ACC)

- The exceedance rate during the recording period (TX_PER_FONCT)
- The annual exceedance rate (TX_PER_FONCT_AN)

➢ **date_ heure_poidscumul.csv** : This file contains the following fields of information (columns) for each of the probabilistic models included in the updating process:

- The name of the probabilistic model (FICHIER) and the folder where it is situated (i.e. C:\……\model1.dat.)
- The exceedance rate during the recording period in the selected stations (TAUX_CUMUL)
- The *a posteriori* weight non normalized (POIDS_ACTU): This values correspond to the values obtained using the equation (8)
- The *a posteriori* weight normalized (POIDS_DEF): This values correspond to the values obtained using the equation (10)

➢ **med_act.gra**: it contains the median seismic hazard curves after the updating process, considering the weights *a posteriori,* in Crisis format*.*

➢ **moy_act.gra**: it contains the mean seismic hazard curves after the updating process, considering the weights *a posteriori,* in Crisis format*.*

➢ **per15_act.gra** and **per85_act.gra**: they contain the percentiles 15% and 85% seismic hazard curves after the updating process, considering the weights *a posteriori,* in Crisis format*.*

The statistical treatment of the *.gra files containing the seismic hazard curves will lead to the definition of the updated response spectra at different return periods.

Finally, it should be noted that all the tests performed are based in comparisons between the seismic hazard curves associated to PGA and the observations expressed in terms of PGA. Nevertheless, the same Bayesian updating process could be applied to seismic hazard curves associated to other spectral periods and compared with observed or estimated REX expressed in terms of the that spectral period.

UPDATE METHOD

TEST NAME : Test 1

GEOTER eDF

Test specifications

Files number : **24**

K value : **1.01**

Acceleration threshold (cm/s²) : **10.0**

REX (Exceedance number) : **25**

Test properties

gmpe :

Sigma :

Mmin :

Others :

Source directory : C:\affaires\2014\1414_EDF_Bayesian_update\fichiers_calculs

Sites - (11)

ANTF	OGDH
IRJO	OGDI
OGAG	OGMO
OGAN	OGTB
OGAV	SAOF
	STET

Main values

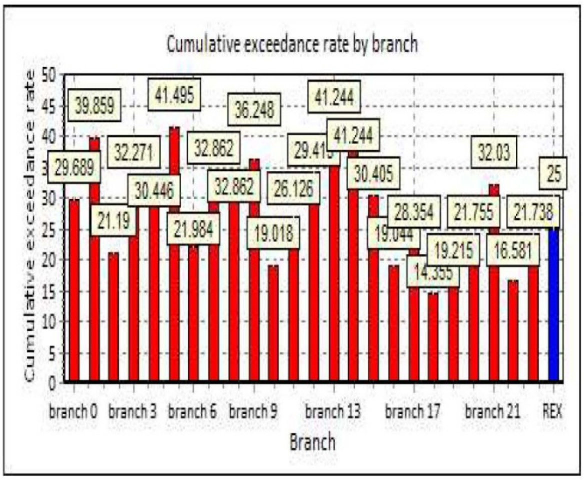
Mean exceedance rate a priori : **28.3094**

Updated rate : **26.0950**

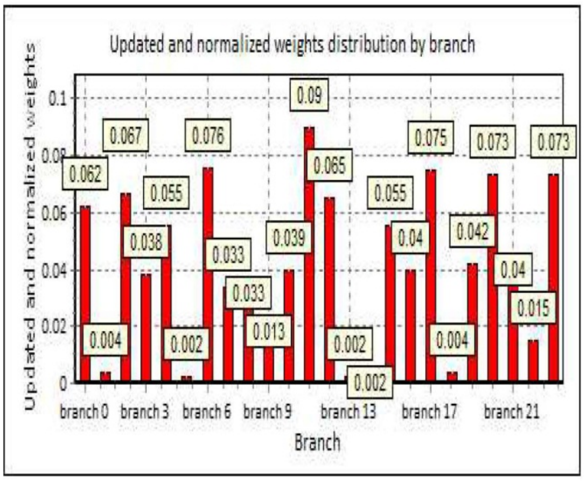
Std deviation of exceedance rate a priori : **8.2270**

Updated std dev. : **5.0865**

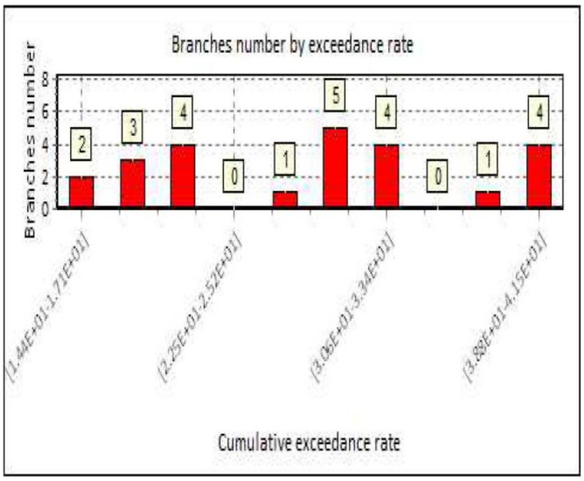
Cumulative exceedance rate by branch



Updated weights by branch



Cumulative exceedance rate distribution



A priori updated comparison

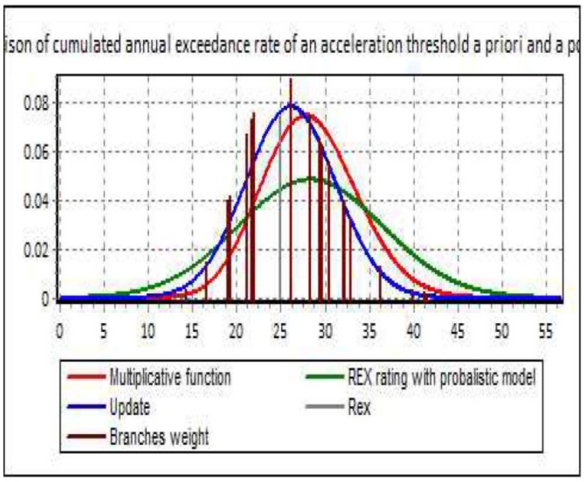


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Figure 47. Example of pdf sheet with the summary of the update of the seismic hazard performed.